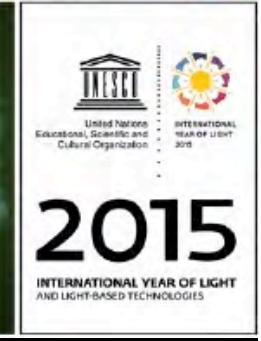
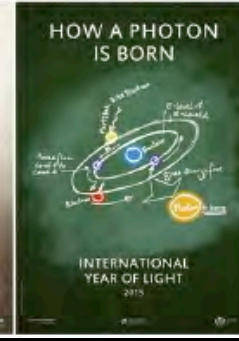
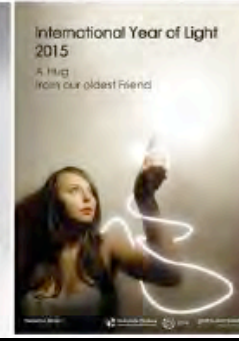
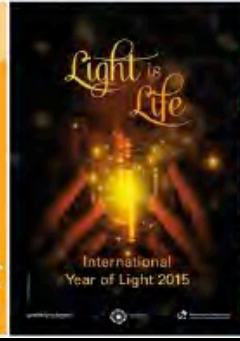
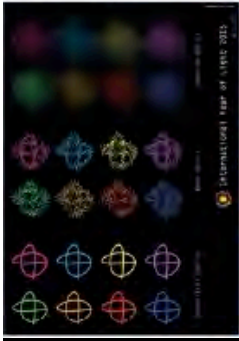
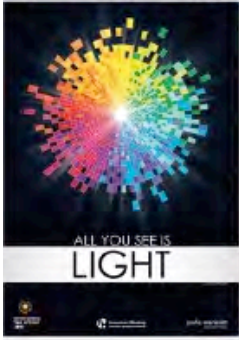
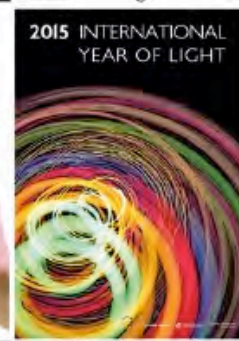
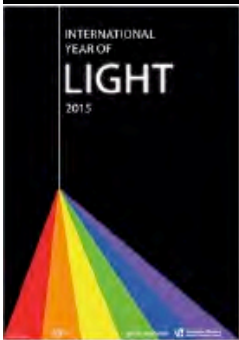


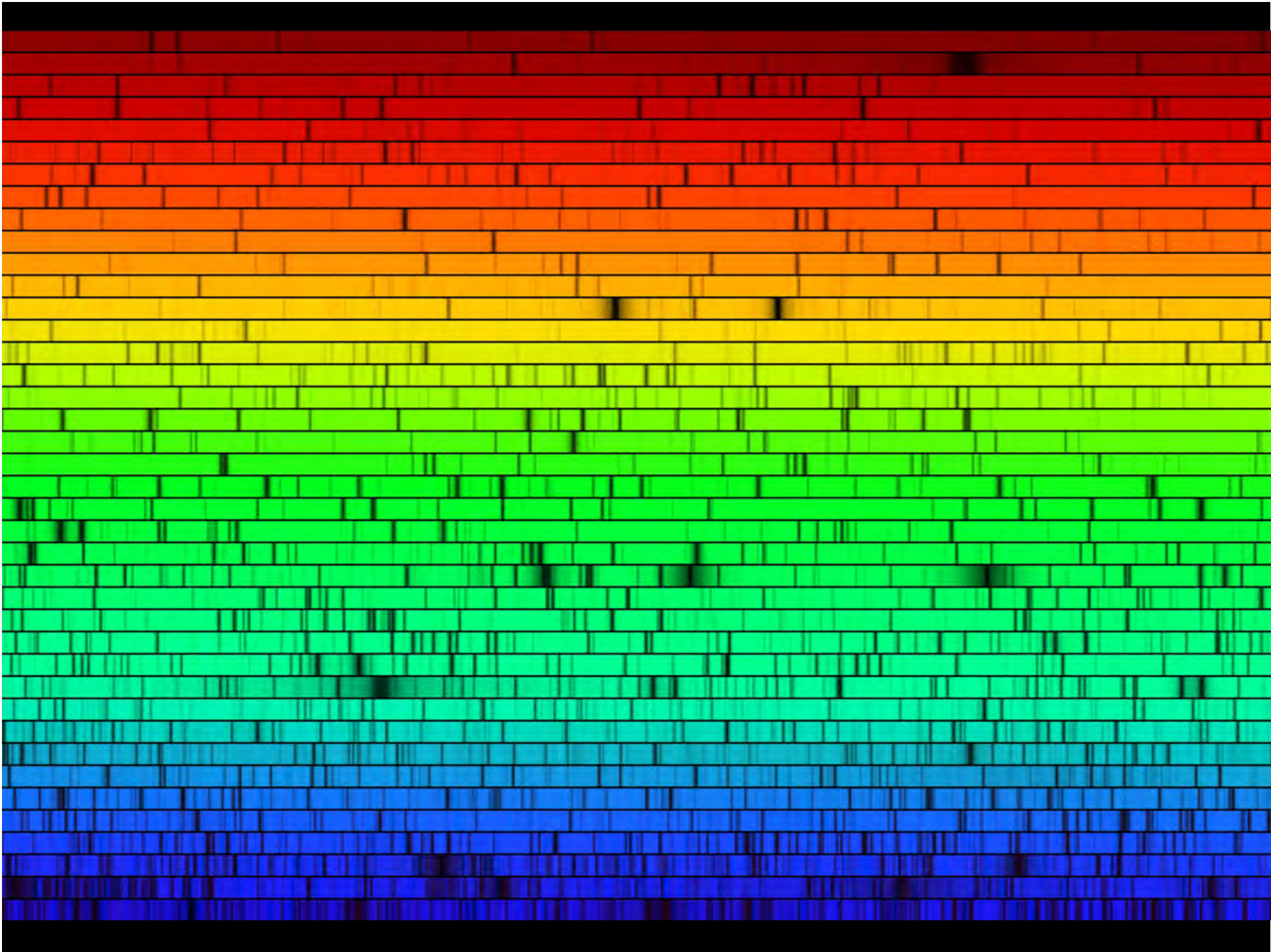
Den Rest meines Lebens werde ich darüber nachdenken,
was Licht ist ! A. Einstein 1916

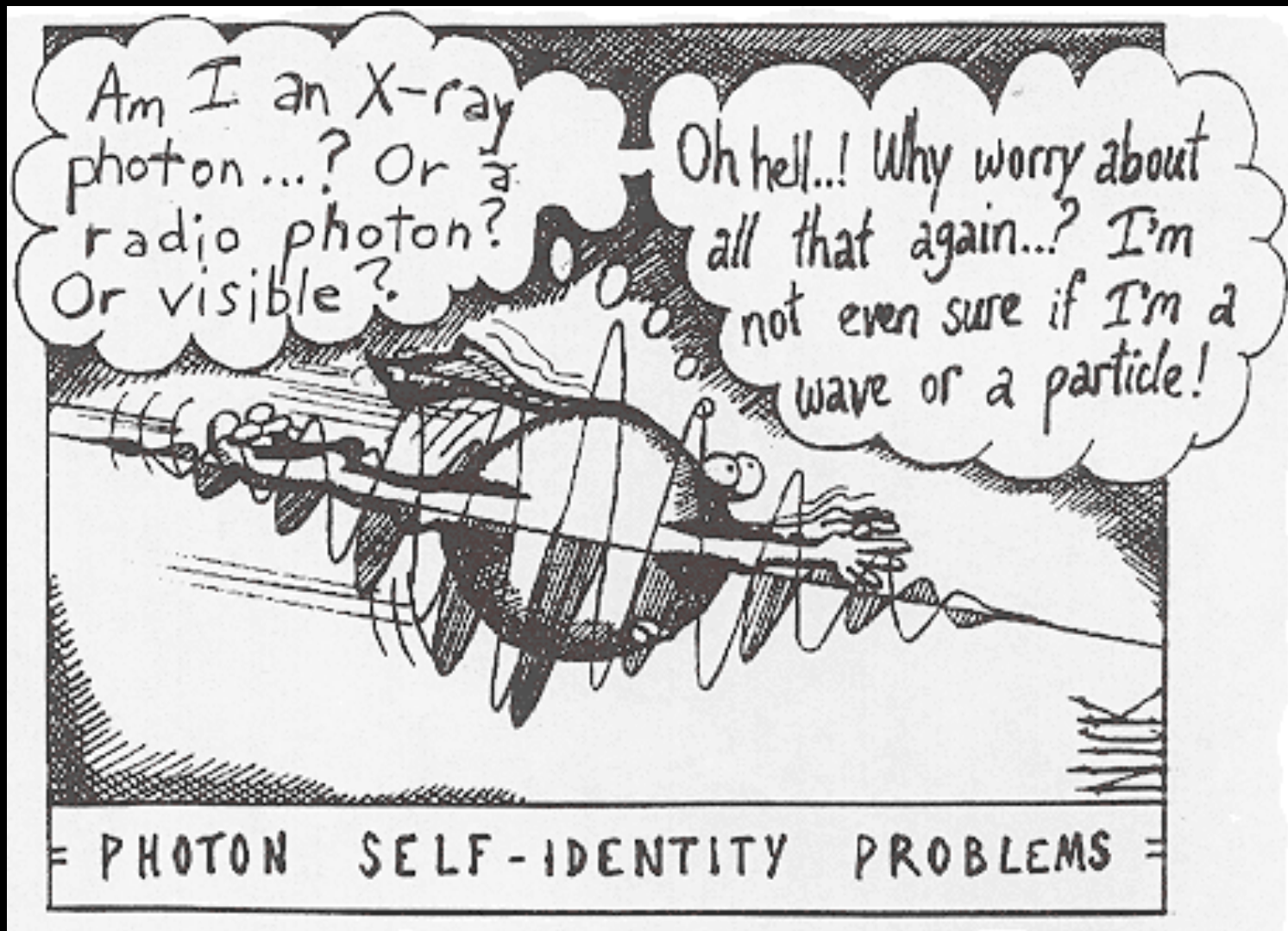
Qu'est-ce que la lumière ?

P. von Ballmoos, IRAP Toulouse

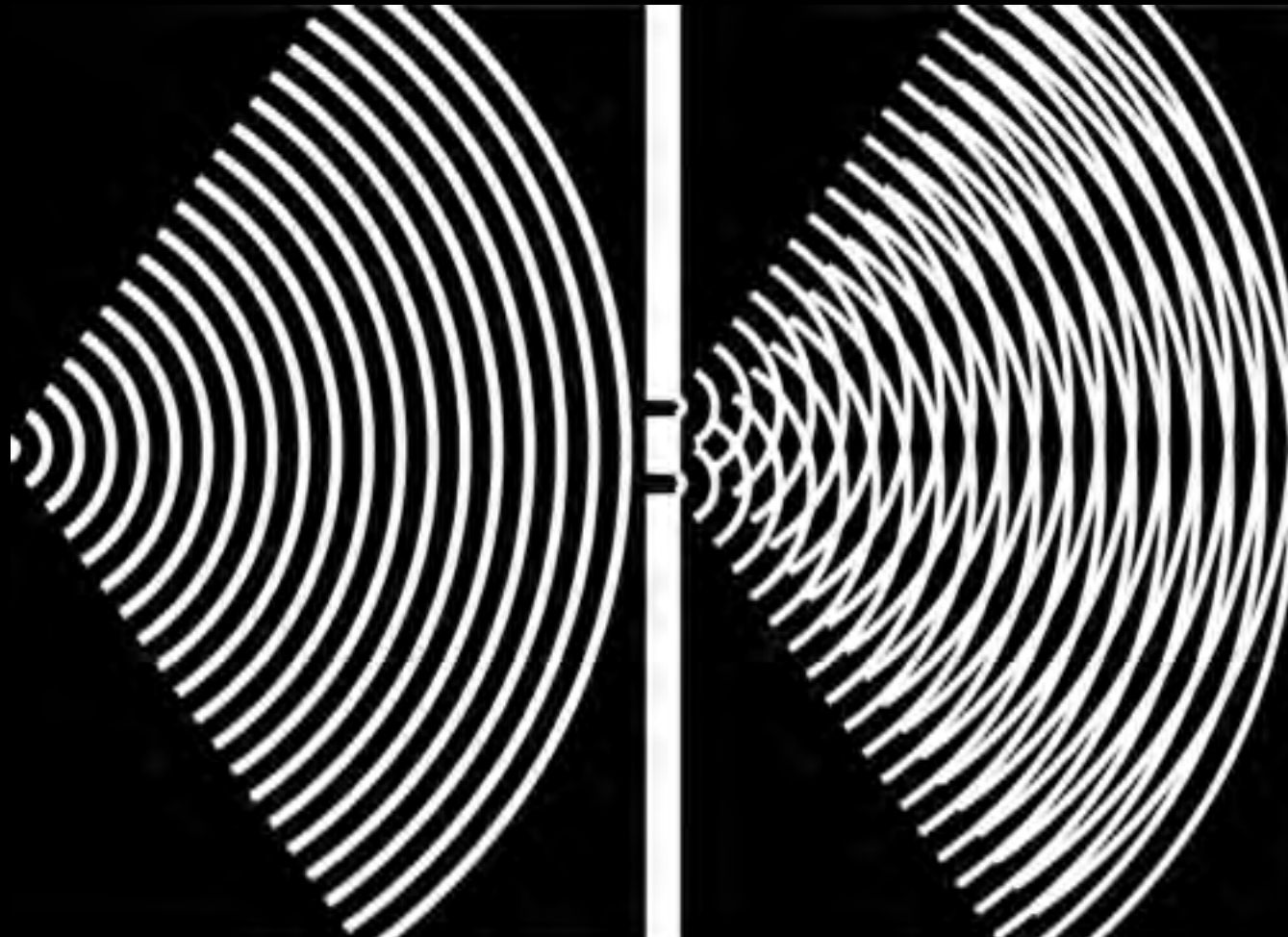








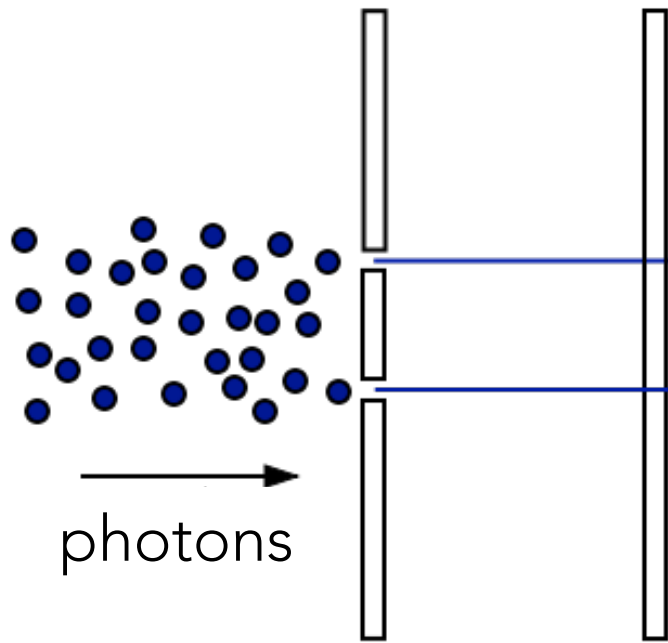
onde ou particule ? Les fentes de Young



onde ?

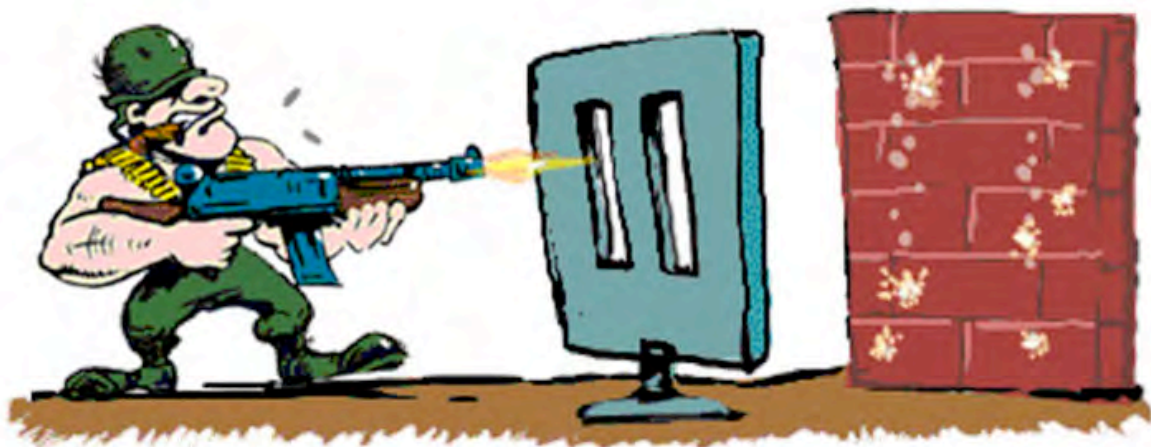


particule ?



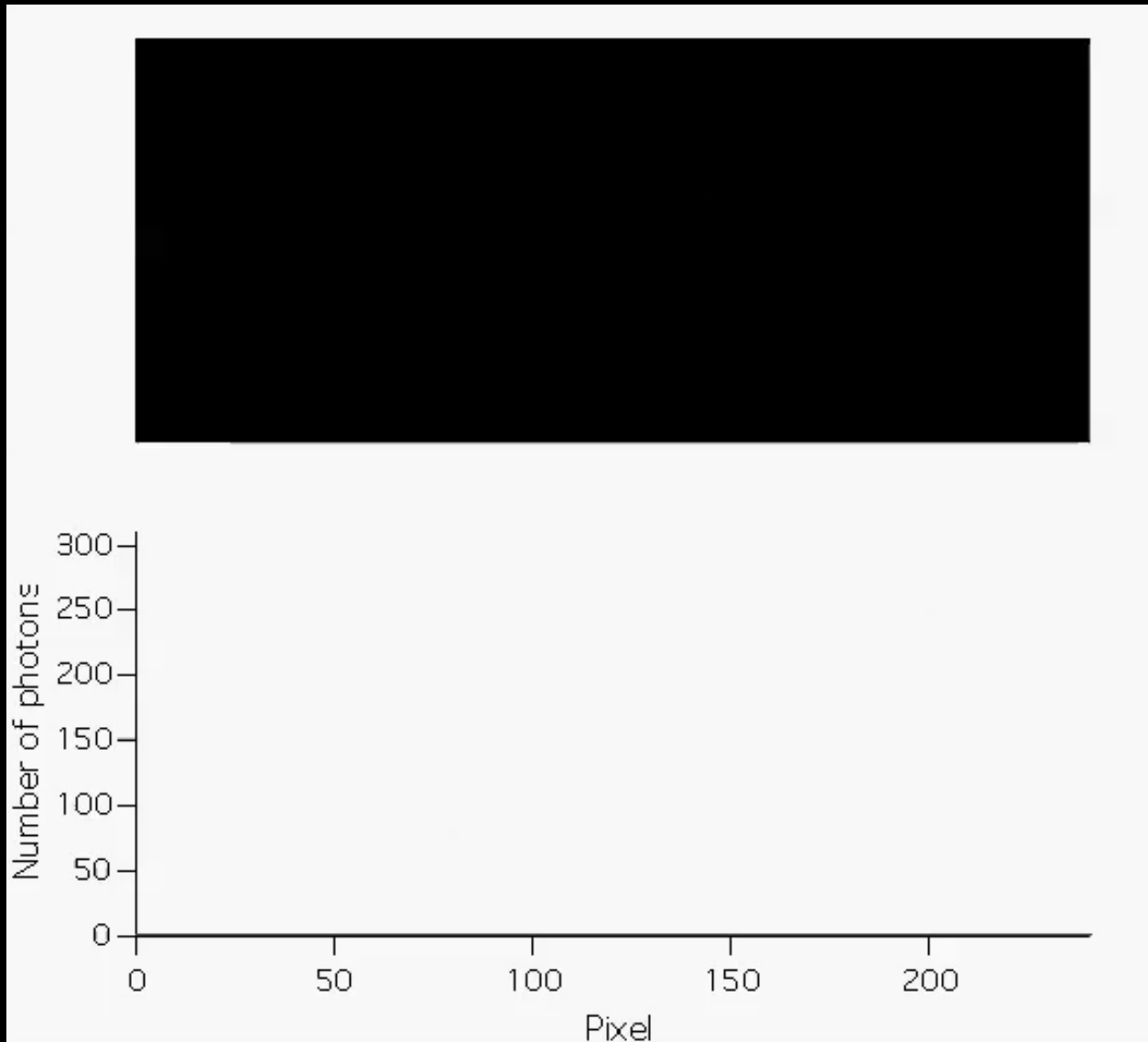
écran
avec
deux
fentes

écran de projection

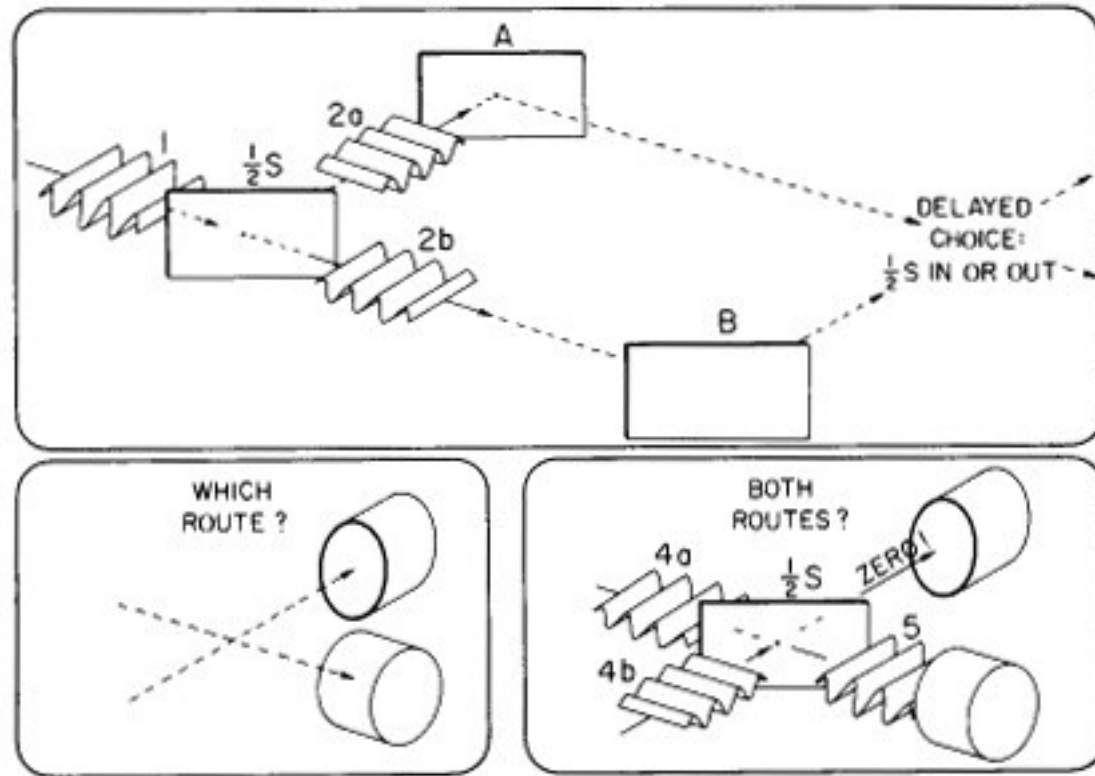


Wheeler's delayed-choice Gedanken-Experiment

Jacques et al 2006

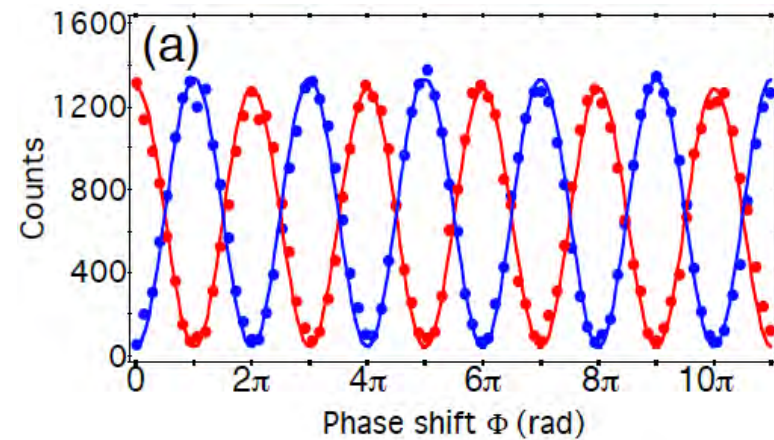
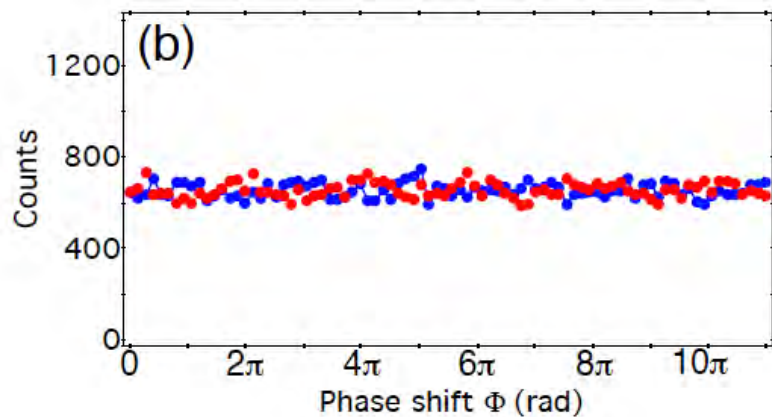
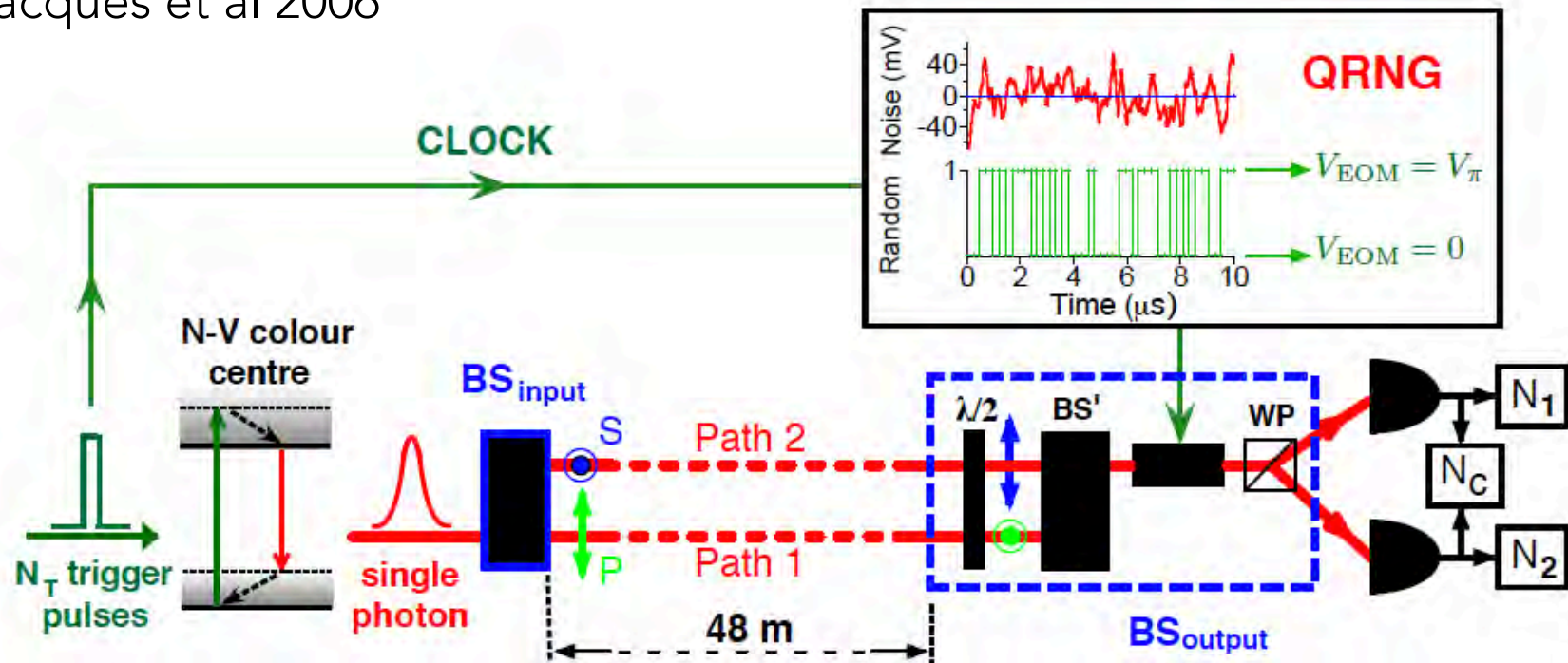


Wheeler's delayed-choice Gedanken-Experiment



Wheeler's delayed-choice Gedanken-Experiment

Jacques et al 2006



L'allégorie de la caverne (Platon)





Dualité onde-corpuscule
La métaphore du cylindre

petit atlas de la lumière



Le rayonnement électromagnétique

radio sub-mm IR visible UV rayons X rayons gamma

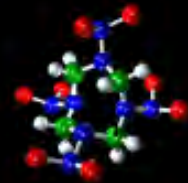
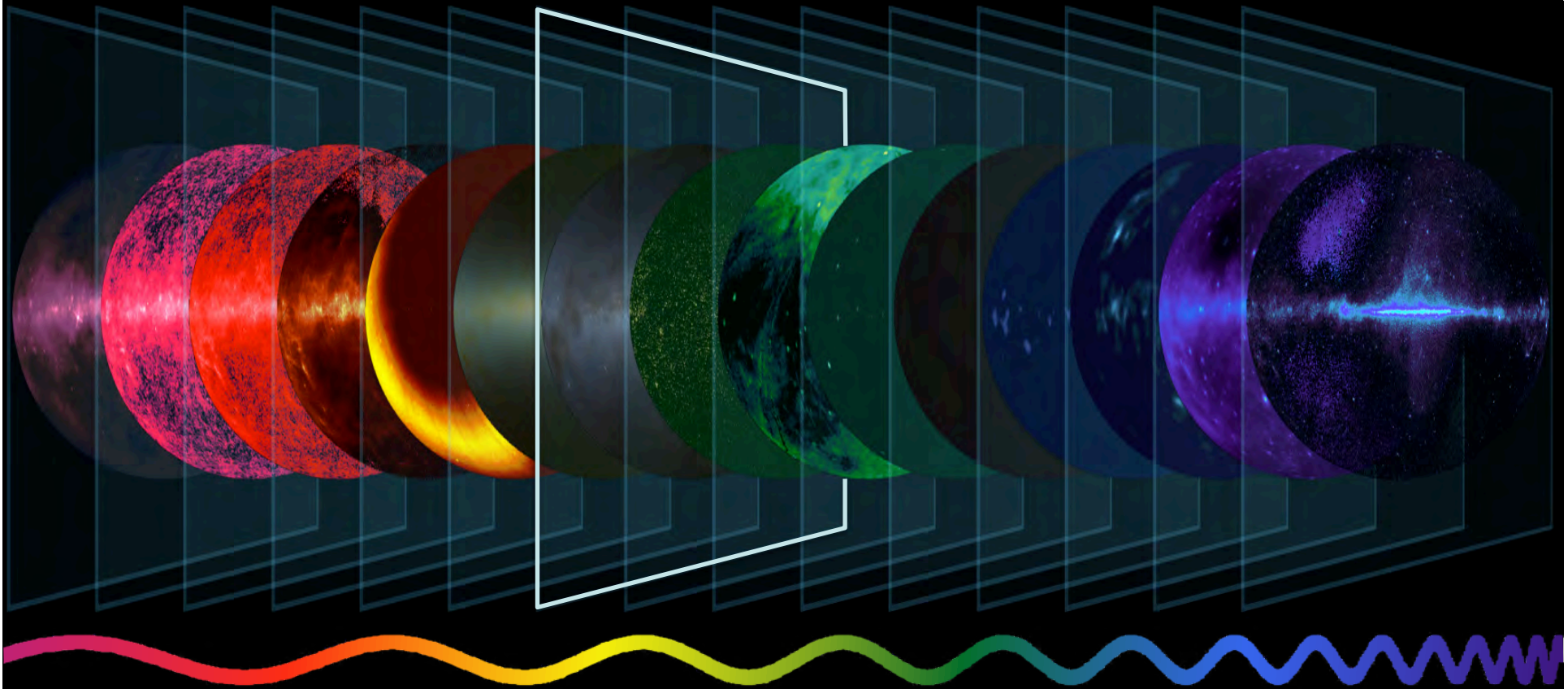


tableau de bord : ondes radio

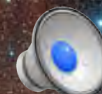
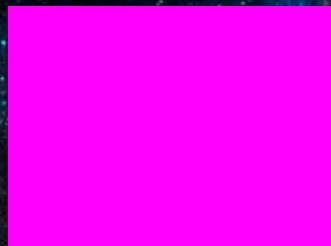


matière neutronique
structure de la Galaxie
quasars
ondes gravitationnelles
etc



le reste de
supernova de la Vela

digitized sky survey

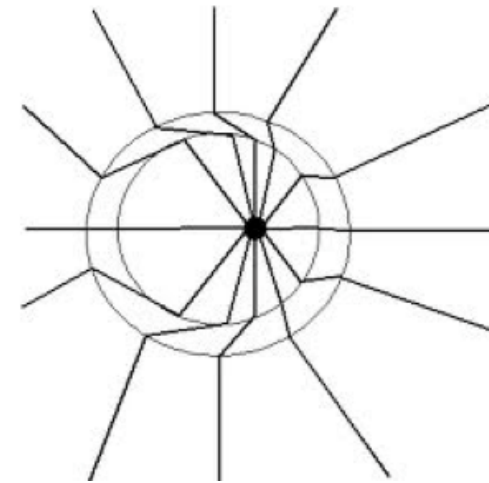


onde électromagnétique

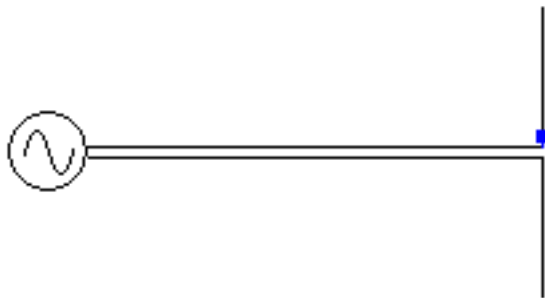
$$\left. \begin{aligned} \nabla \cdot \mathbf{E} &= 0 \\ \nabla \times \mathbf{E} &= -\mu_0 \frac{\partial \mathbf{H}}{\partial t} \\ \nabla \cdot \mathbf{H} &= 0 \\ \nabla \times \mathbf{H} &= \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \end{aligned} \right\}$$

$$\left. \begin{aligned} \frac{\partial^2 \mathbf{E}}{\partial t^2} - c_0^2 \cdot \nabla^2 \mathbf{E} &= 0 \\ \frac{\partial^2 \mathbf{B}}{\partial t^2} - c_0^2 \cdot \nabla^2 \mathbf{B} &= 0 \end{aligned} \right\}$$

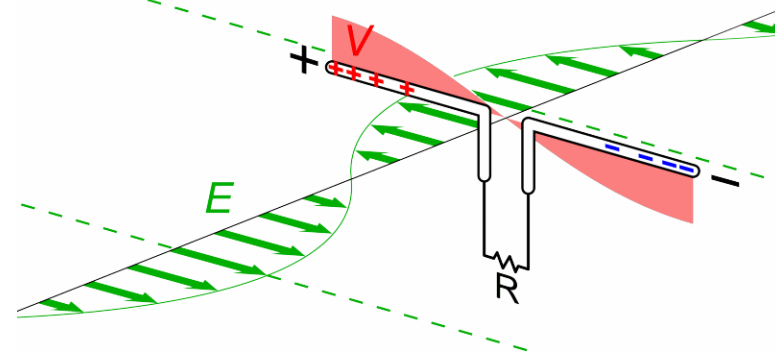
$$c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 2.99792458 \times 10^8 \text{ m/s}$$



émission



réception



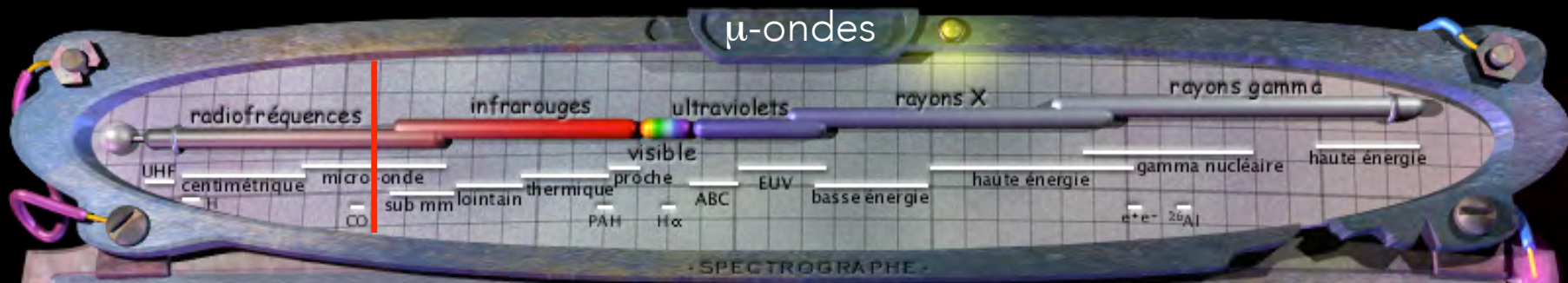


LA LUMIÈRE
PARCOURT
299.792.458
MÈTRES À
LA SECONDE

C'EST SURTOUT
VRAI LA NUIT

EN PLEIN
SOLEIL, ELLE
FAIT MOINS
LA MALIGNE !

tableau de bord : micro-ondes



fond cosmologique
age précis de l'Univers
geometrie de l'Univers



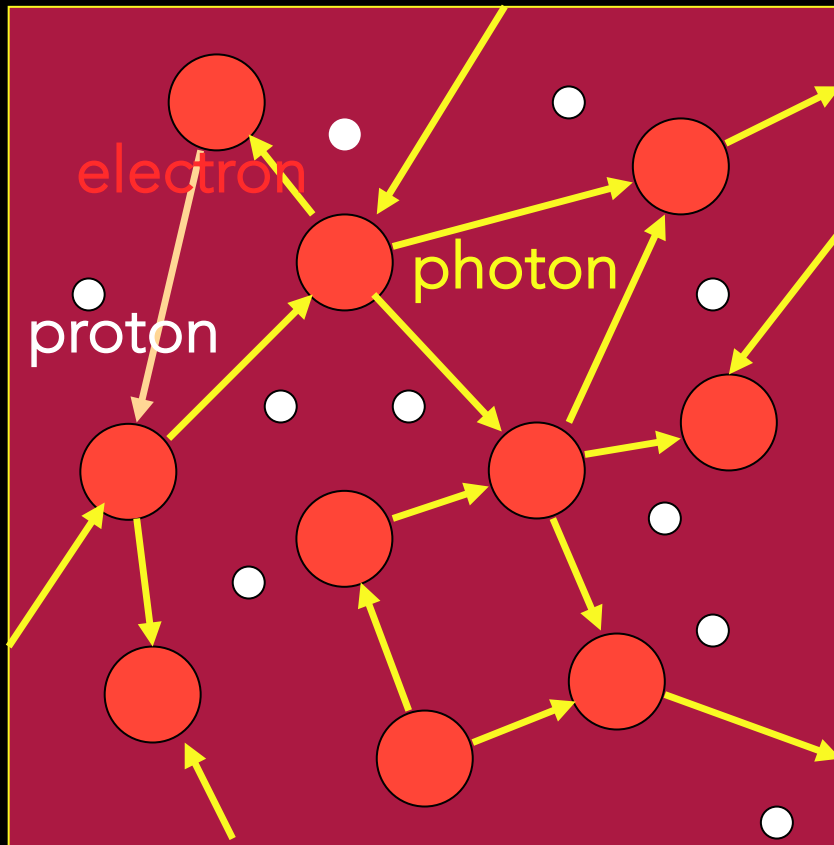
PLANCK

=> L'Univers a 13.8 Milliards d'années



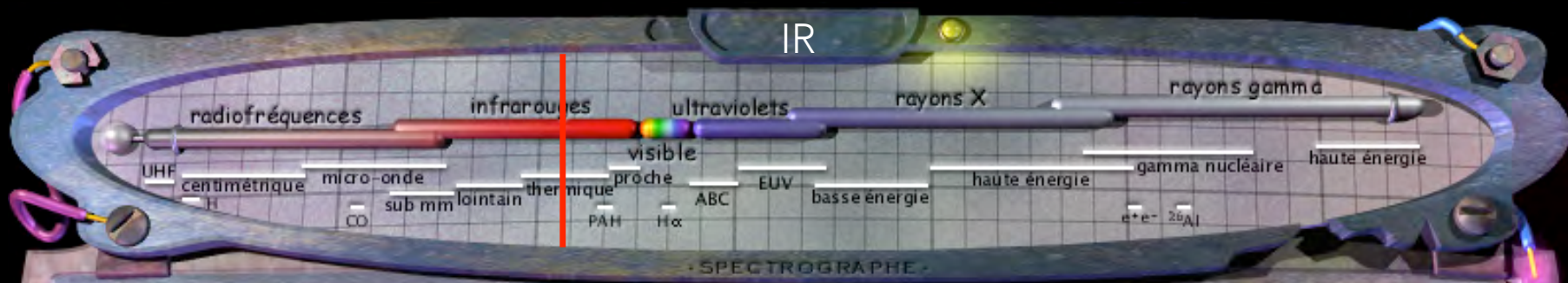
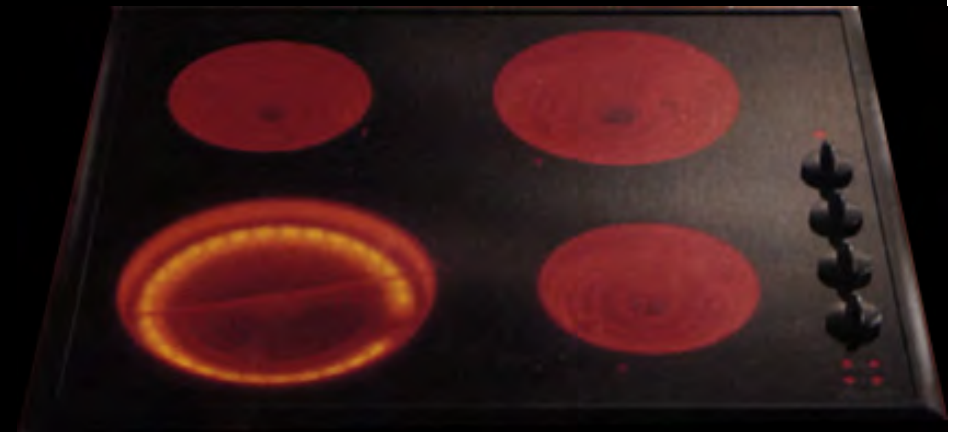
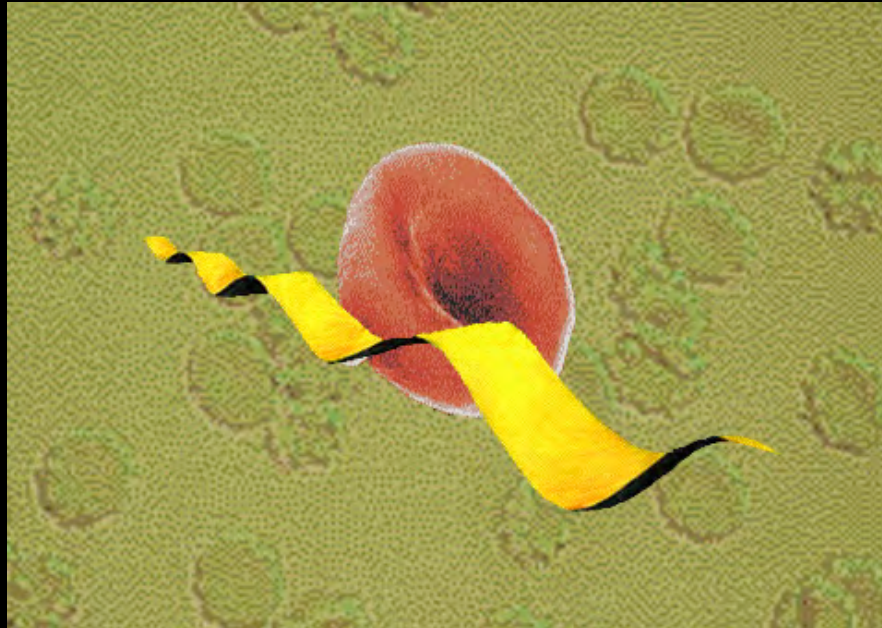
380'000 ans après le Big Bang lumière et matière "divorcent"

avant

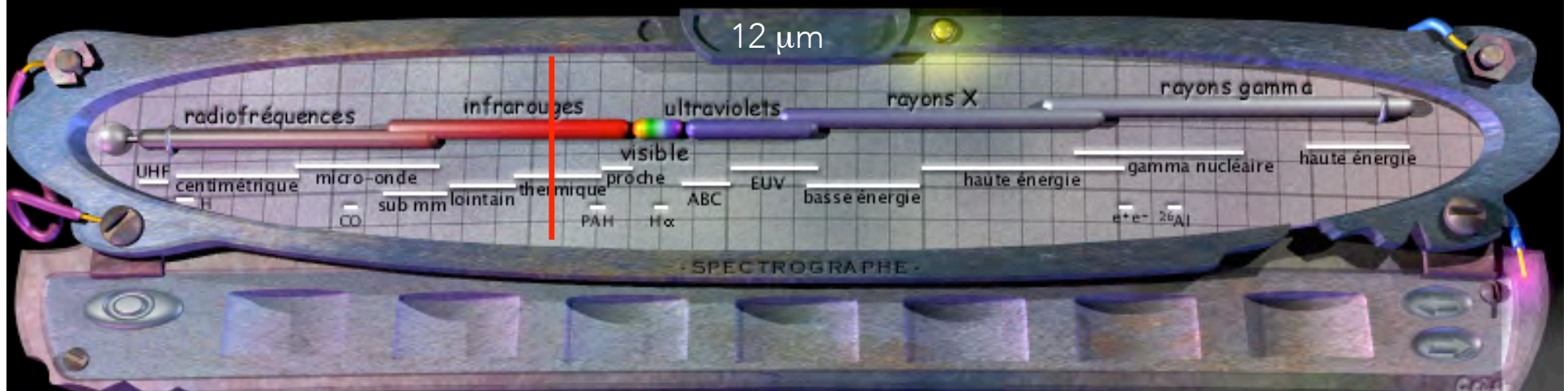


l'Univers devient transparent – les atomes (H) naissent

tableau de bord : infrarouge



nuages protostellaires
disques protoplanétaires
eau
molécules ... organiques
Galaxies infrarouges
masers ...



corps noir

6000 K



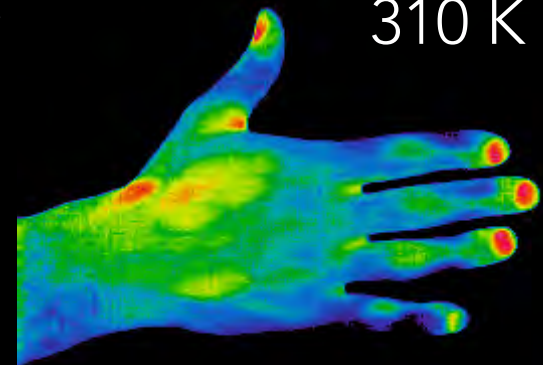
3000 K



800 K



310 K



Corps Noir - emission du soleil, de la terre ...

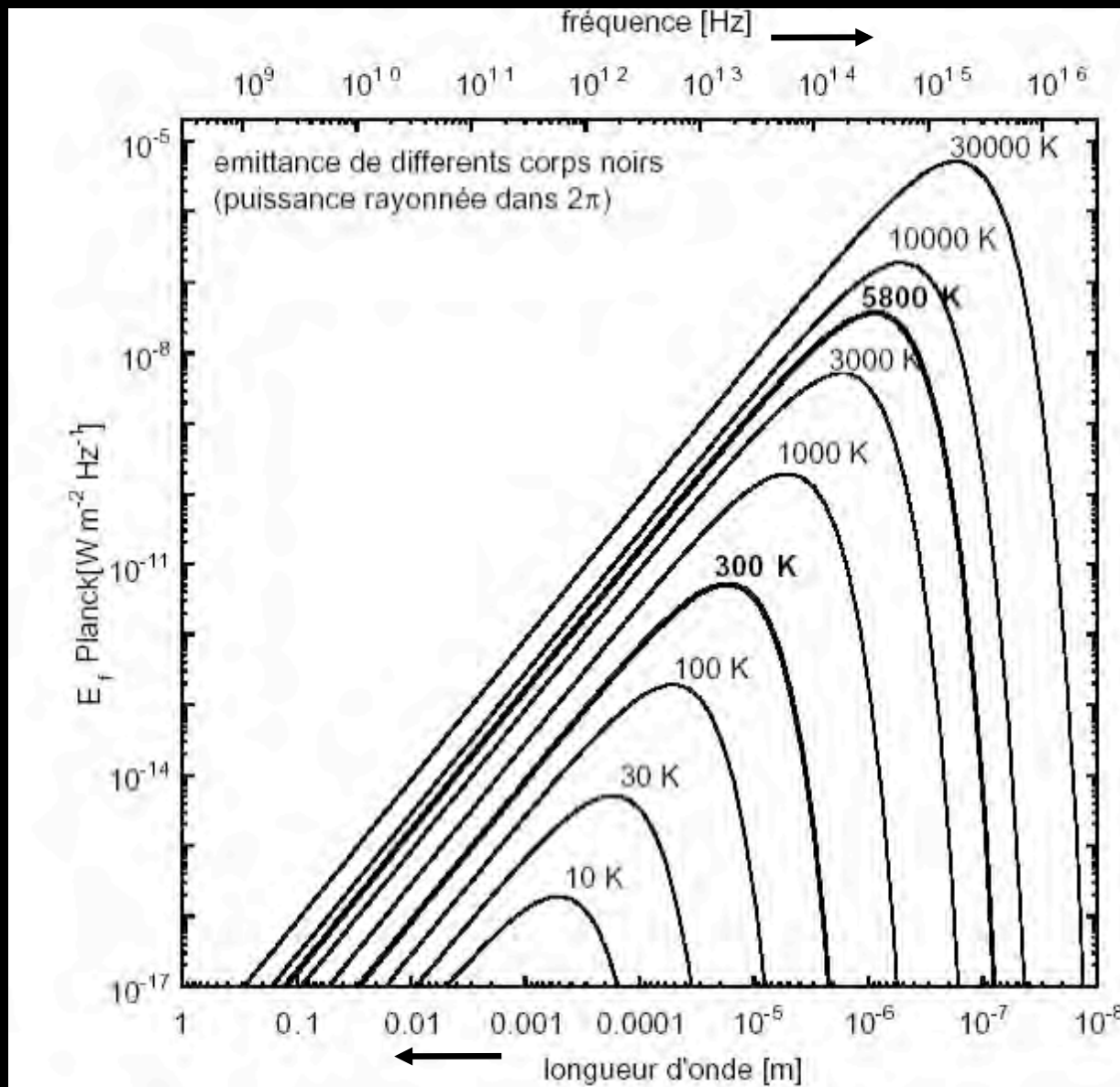
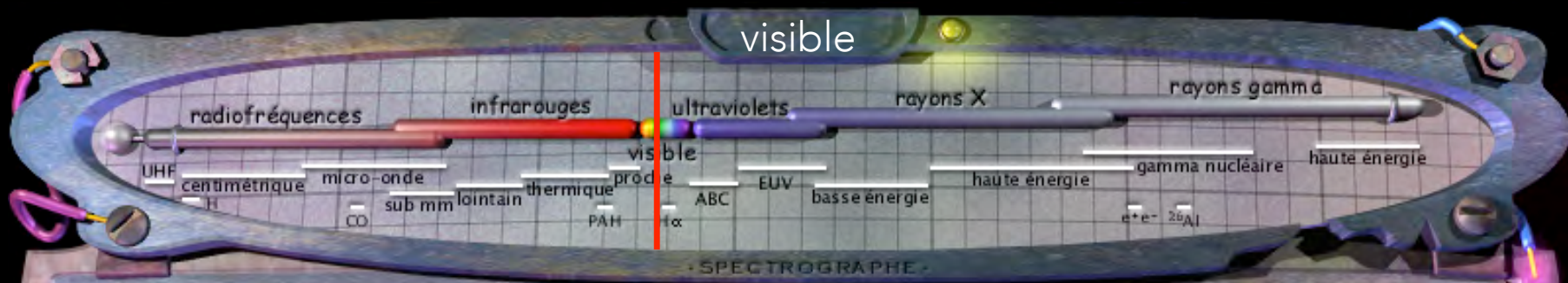
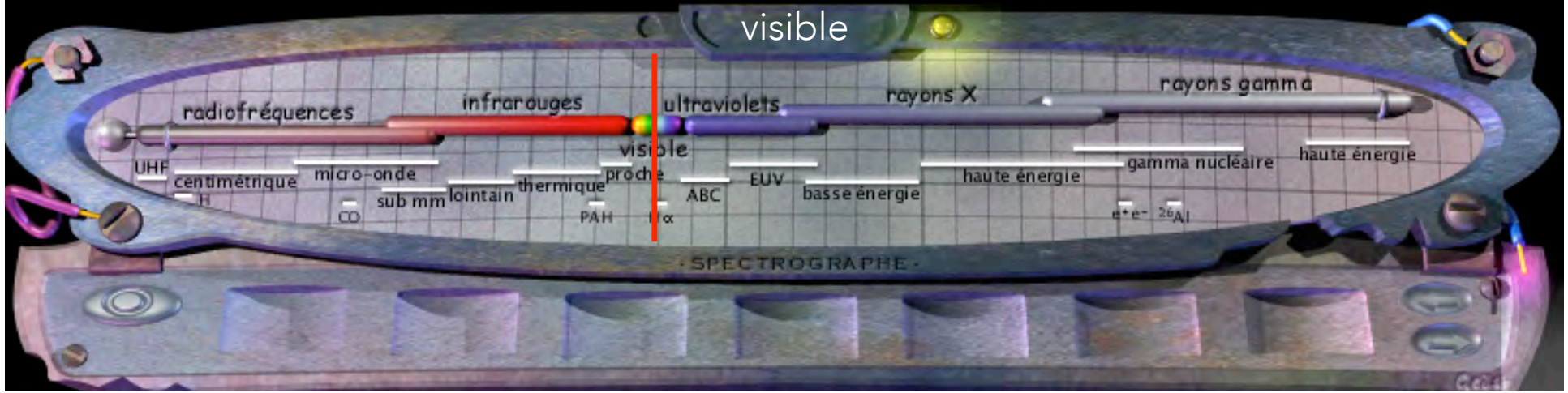


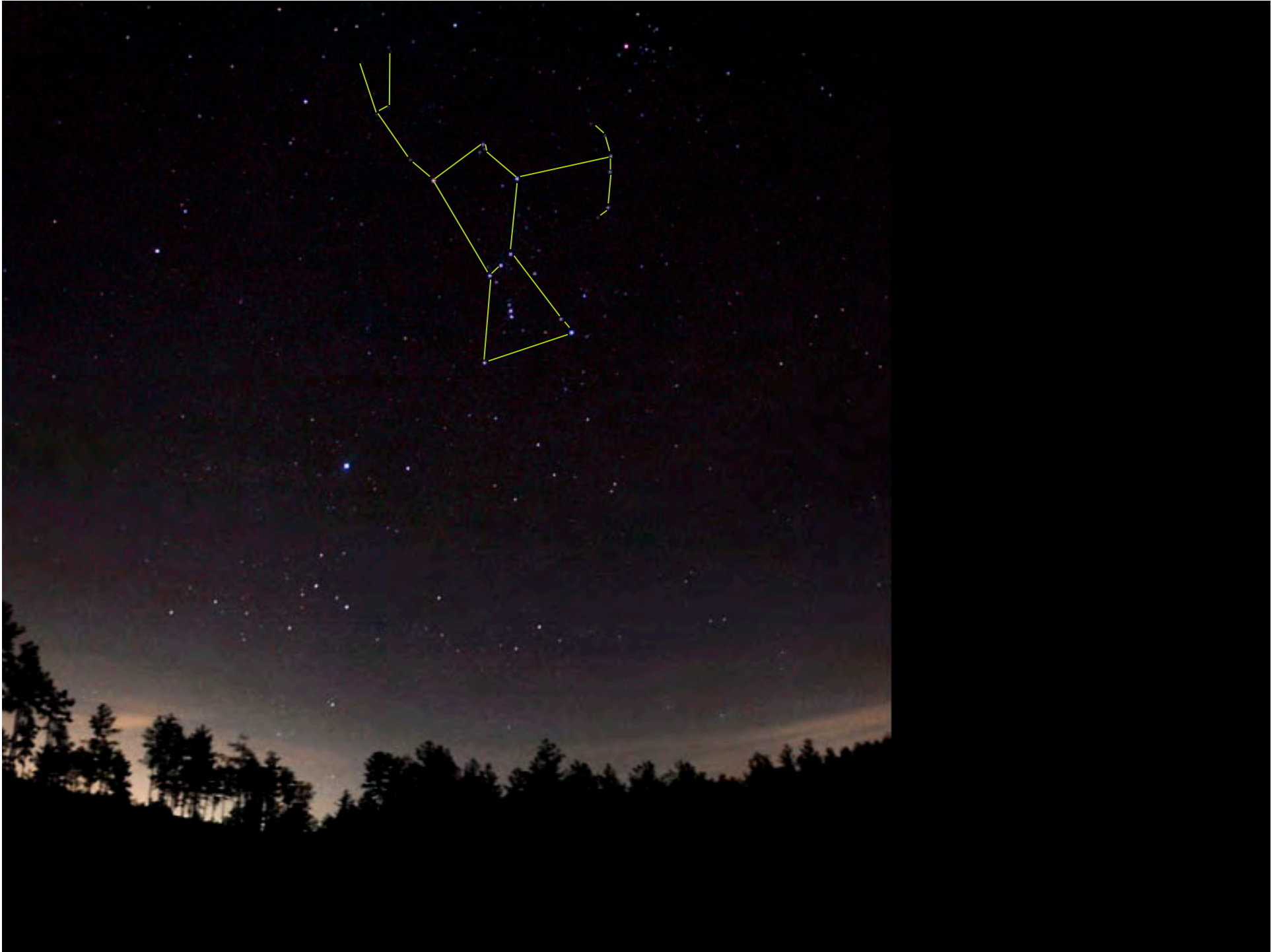
tableau de bord : lumière visible



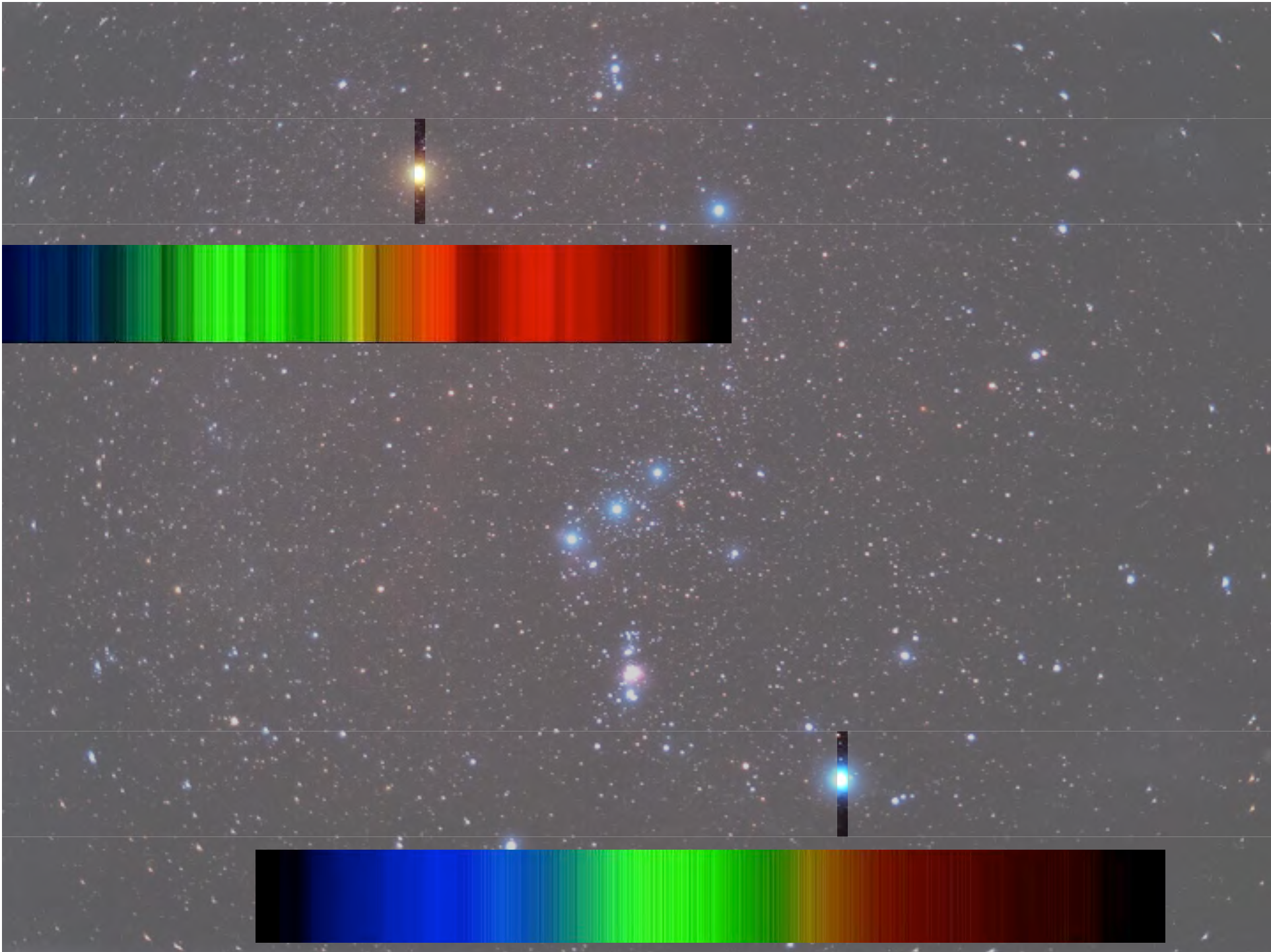
cycle de la matière
expansion de l'Univers
architecture de l'Univers
matière noire
exoplanètes
énergie sombre
etc ...



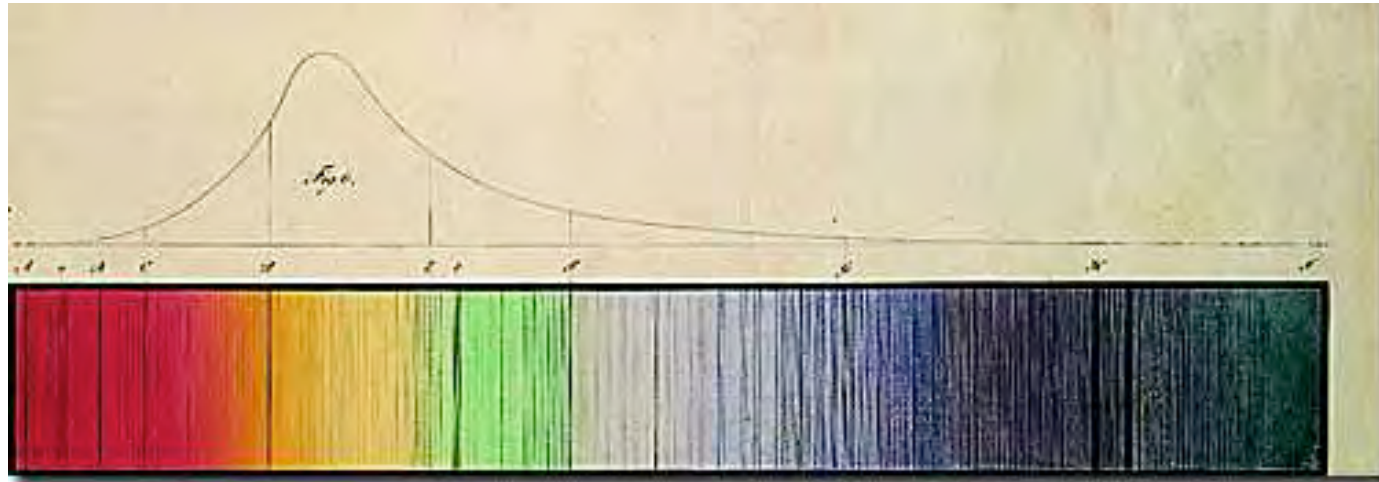






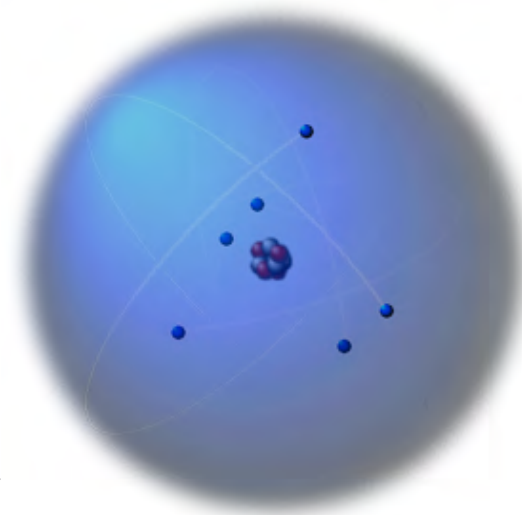


les raies spectrales - 1814 Josef Fraunhofer

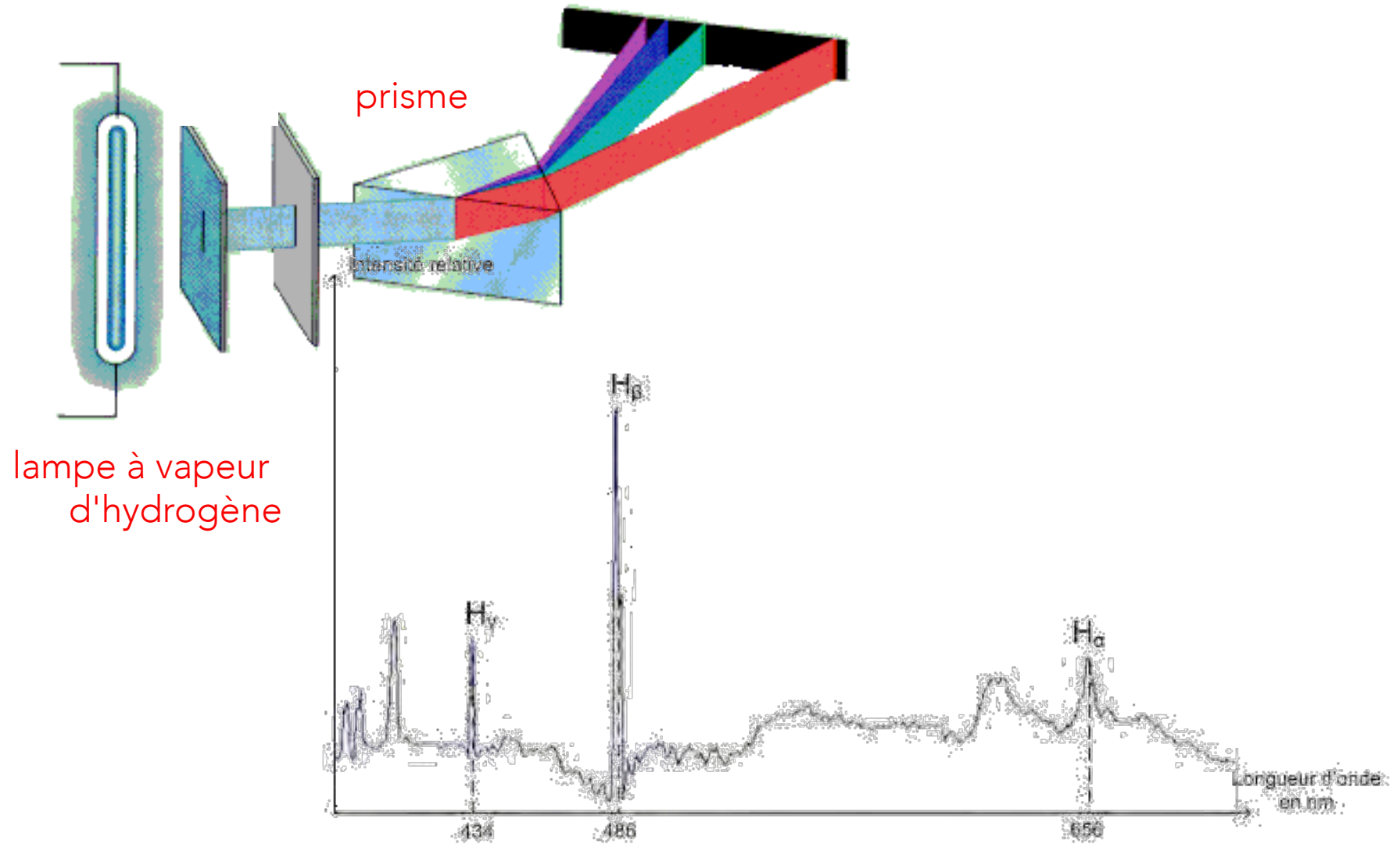


spectre visible du soleil

spectroscopie atomique
-> chimie et physique moderne !



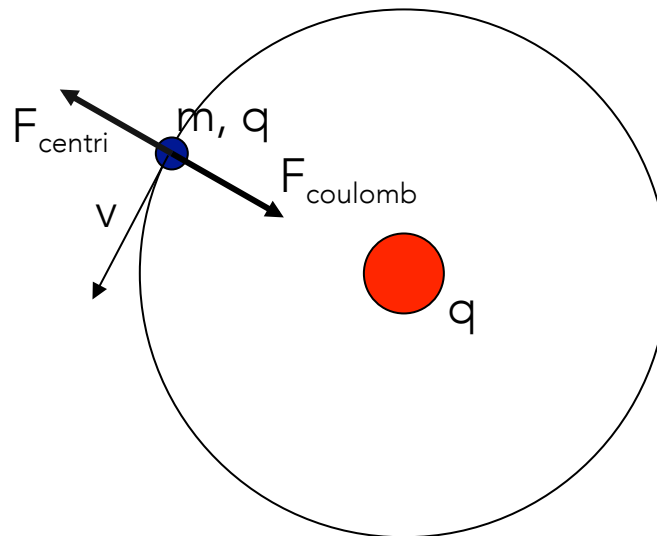
le spectre d'émission de l'hydrogène



stabilité de la matière ordinaire - atome de Bohr

Un électron est en rotation autour d'un proton
on calcule - pour une orbite circulaire - l'équilibre entre :

force électrostatique et force centrifuge



$$F_{\text{coulomb}} = \frac{-q^2}{4\pi\epsilon_0 r^2} = \frac{mv^2}{r} = F_{\text{centri}}$$

L'atome d'hydrogène d'après Bohr

$$F_{\text{coulomb}} = \frac{-q^2}{4\pi\epsilon_0 r^2} = \frac{mv^2}{r} = F_{\text{centri}}$$

idée de Bohr : le moment angulaire L de l'électron est quantisé c.a.d.

$$L = mvr = n\hbar \quad \Rightarrow \quad v = n\hbar / mr$$

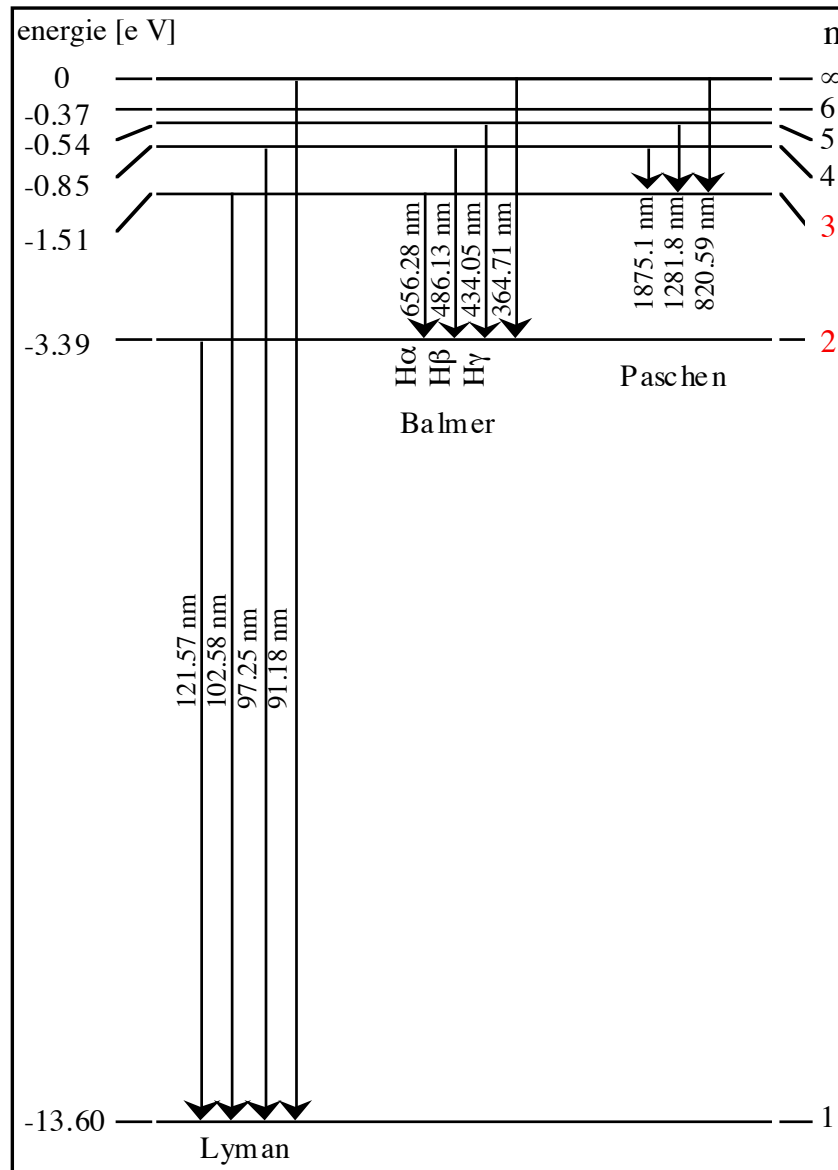
$$\text{L'énergie potentielle devient } E_{\text{pot}} = \frac{-q^2}{4\pi\epsilon_0 r} = \frac{-mq^4}{4\epsilon_0^2 n^2 \hbar^2}$$

$$\text{avec } r_n = \frac{n^2 4\pi\hbar^2 \epsilon_0}{m_e q^2} \quad \text{rayon de Bohr}$$

E_{cin} étant $-1/2$ de E_{pot} (voir aussi théorème du viriel), l'énergie totale E , composé de l'énergie potentielle E_{pot} et de l'énergie cinétique E_{cin} , devient

$$E = \frac{-mq^4}{8\epsilon_0^2 n^2 \hbar^2}$$

Les transitions de l'atome d'hydrogène

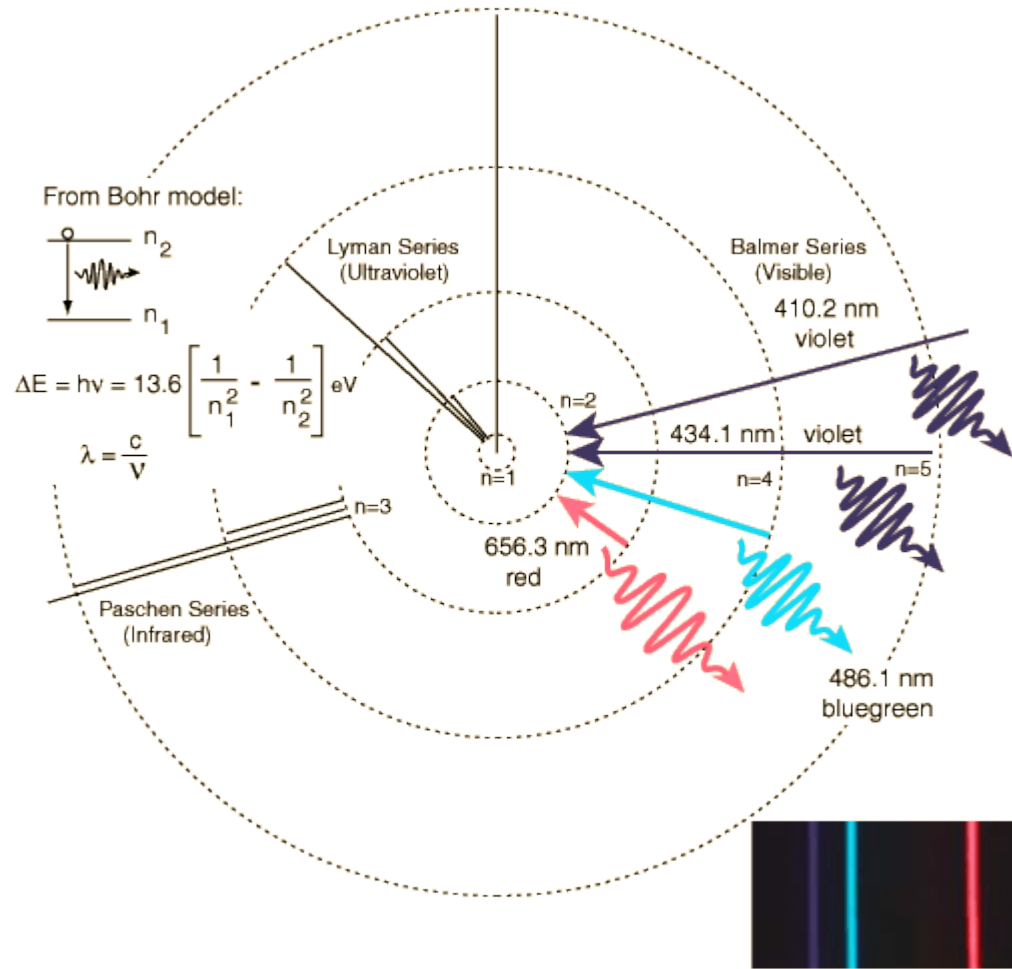


On décrit les états énergétiques (en première approximation) par une seule variable n, le nombre quantique principal

$$E = -E_0/n^2$$

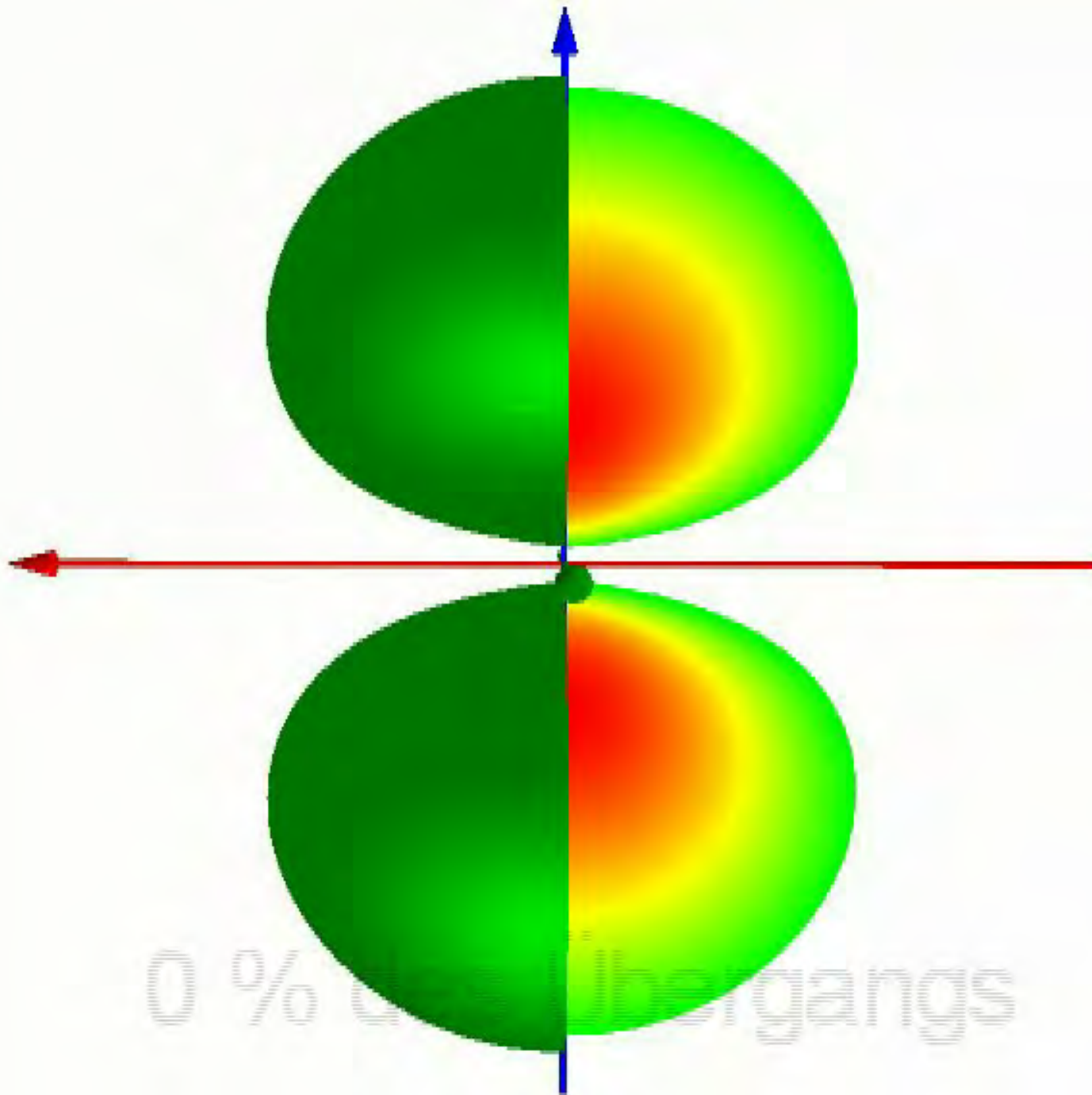
la transition de l'orbite n=3 vers n=2 correspond à une longueur d'onde de 6562.78 Å; dans le spectre de l'hydrogène on mesure une raie à 6562.793 Å (Série de Balmer).

Niveaux et transitions électroniques de l'atome d'hydrogène



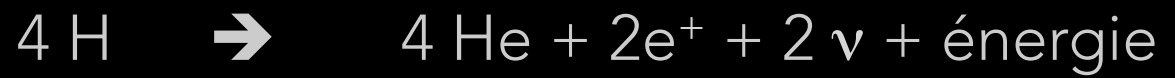
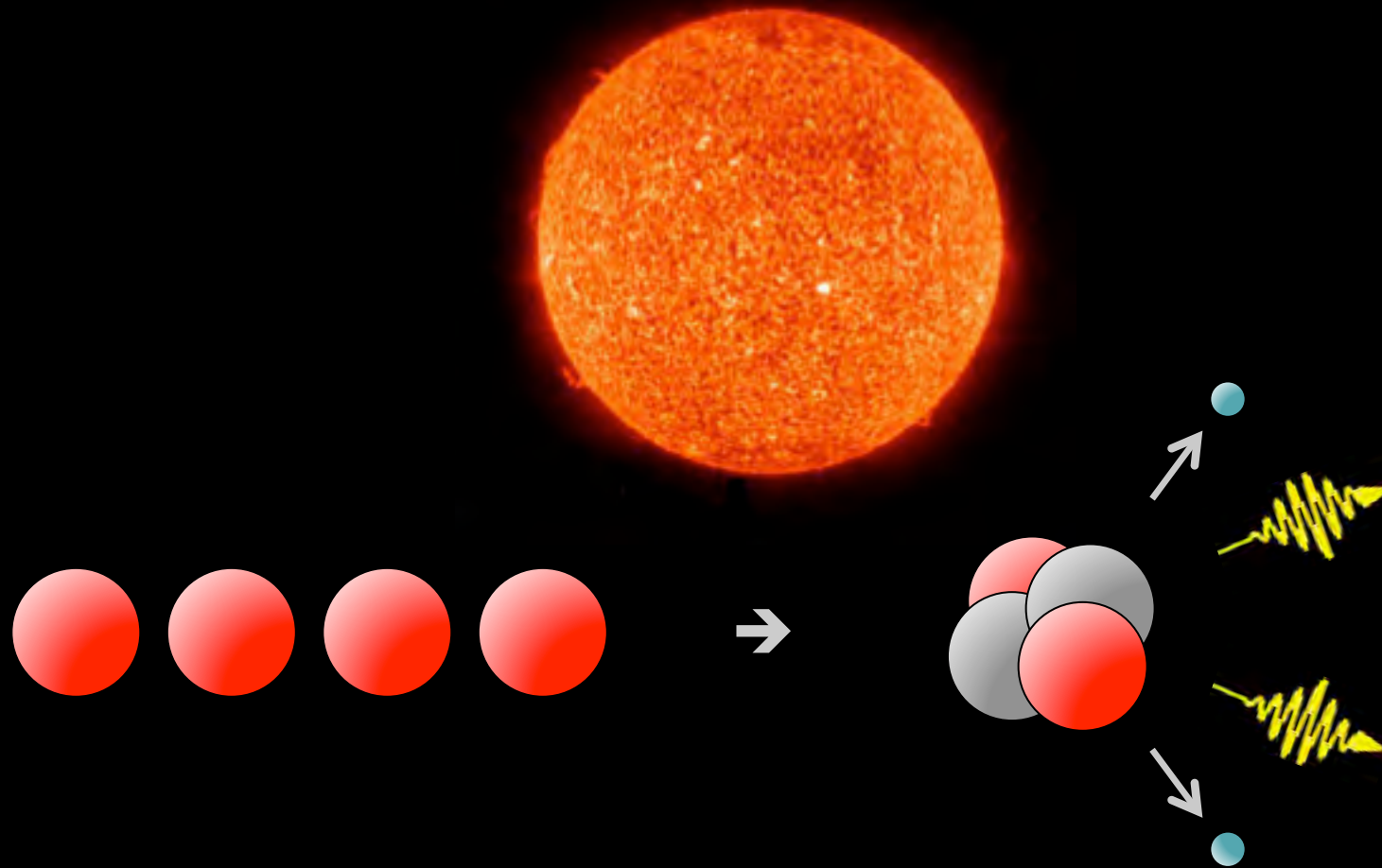
Analyse chimique
des étoiles
par spectroscopie

Chaque élément chimique est caractérisé par des lignes d'absorption et d'émission à des fréquences (longueurs d'onde) qui lui sont spécifiques

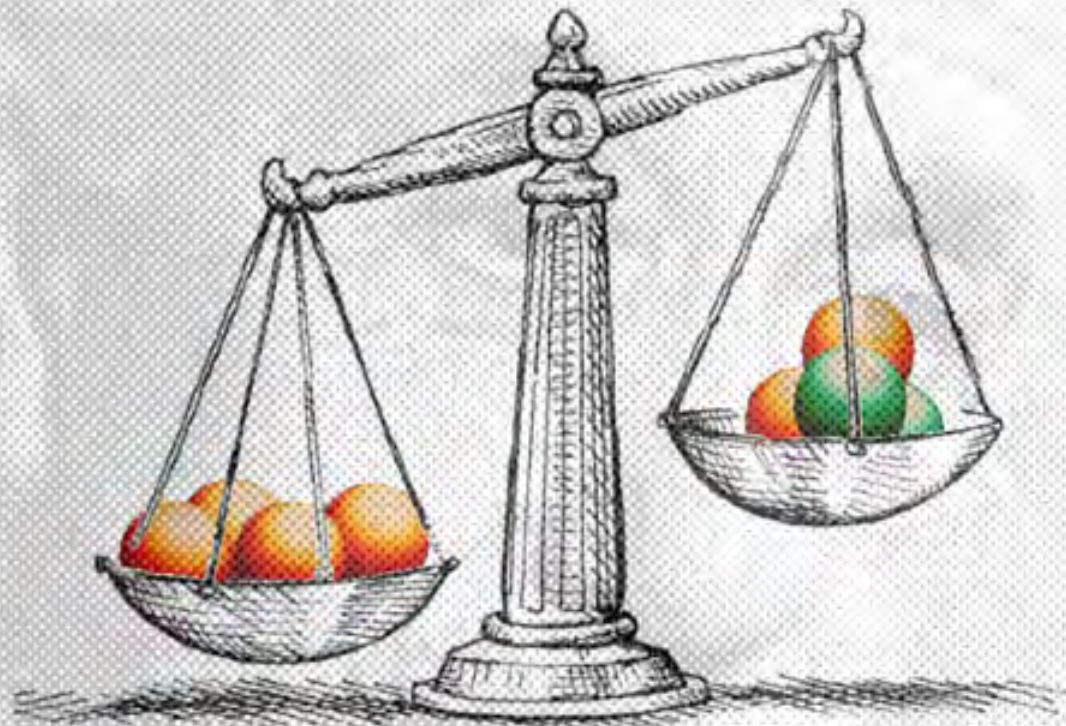


0 % Übergangs

La fusion H \rightarrow He dans le Soleil



$$E = mc^2$$



} Δm

lumière visible ...



sombore

Paradoxe d'Olbers

lumière visible ?

*Slide your hand inside.
Visible light is can only be seen
when an object is present.
Desliza tu mano al interior.
La luz visible sólo se percibe por
la presencia de un objeto.*

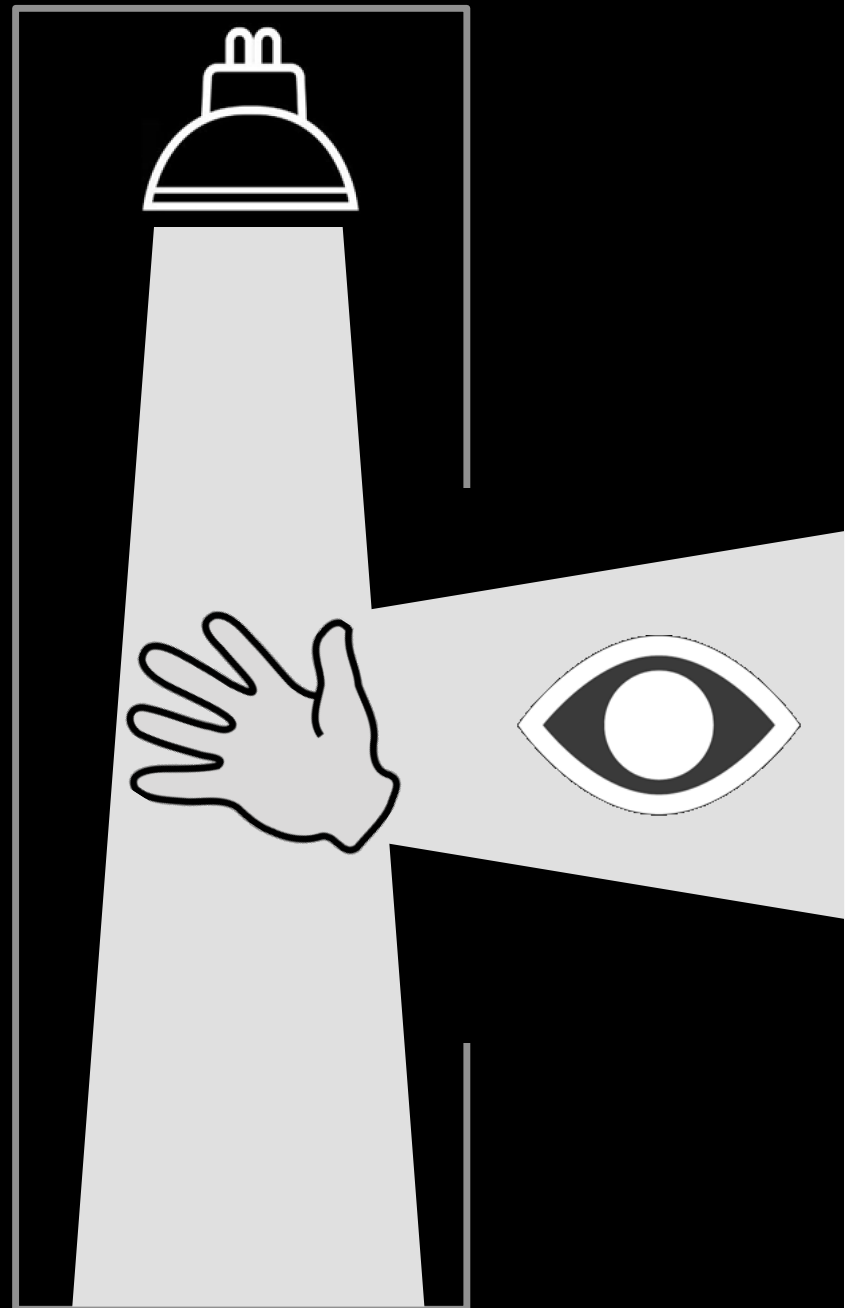
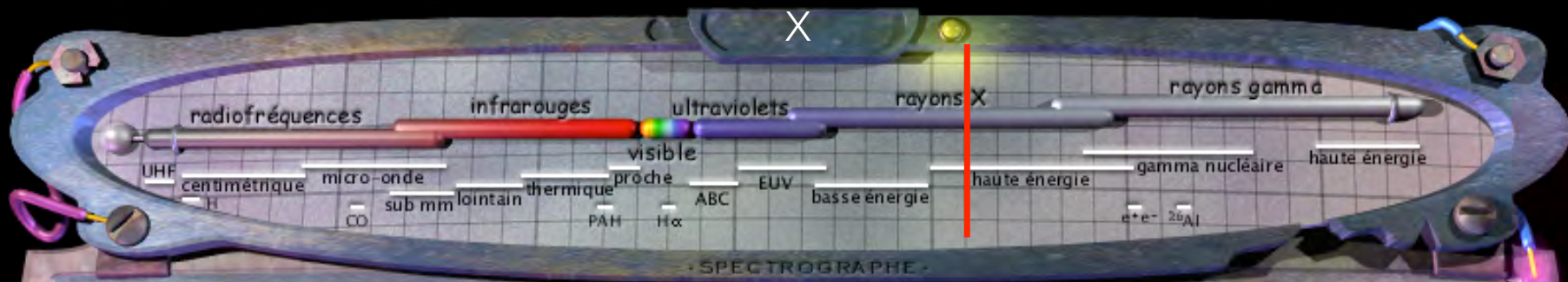
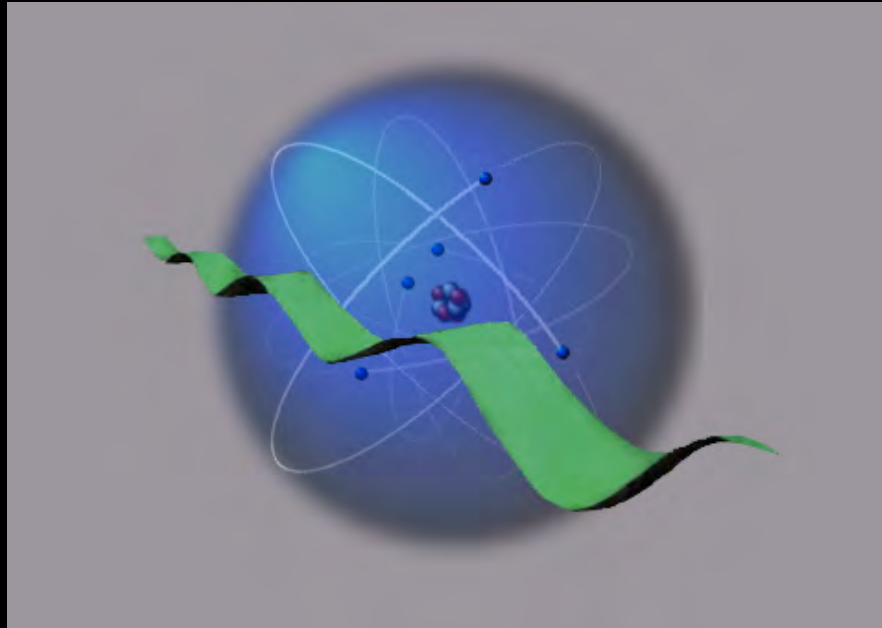


tableau de bord : rayons X

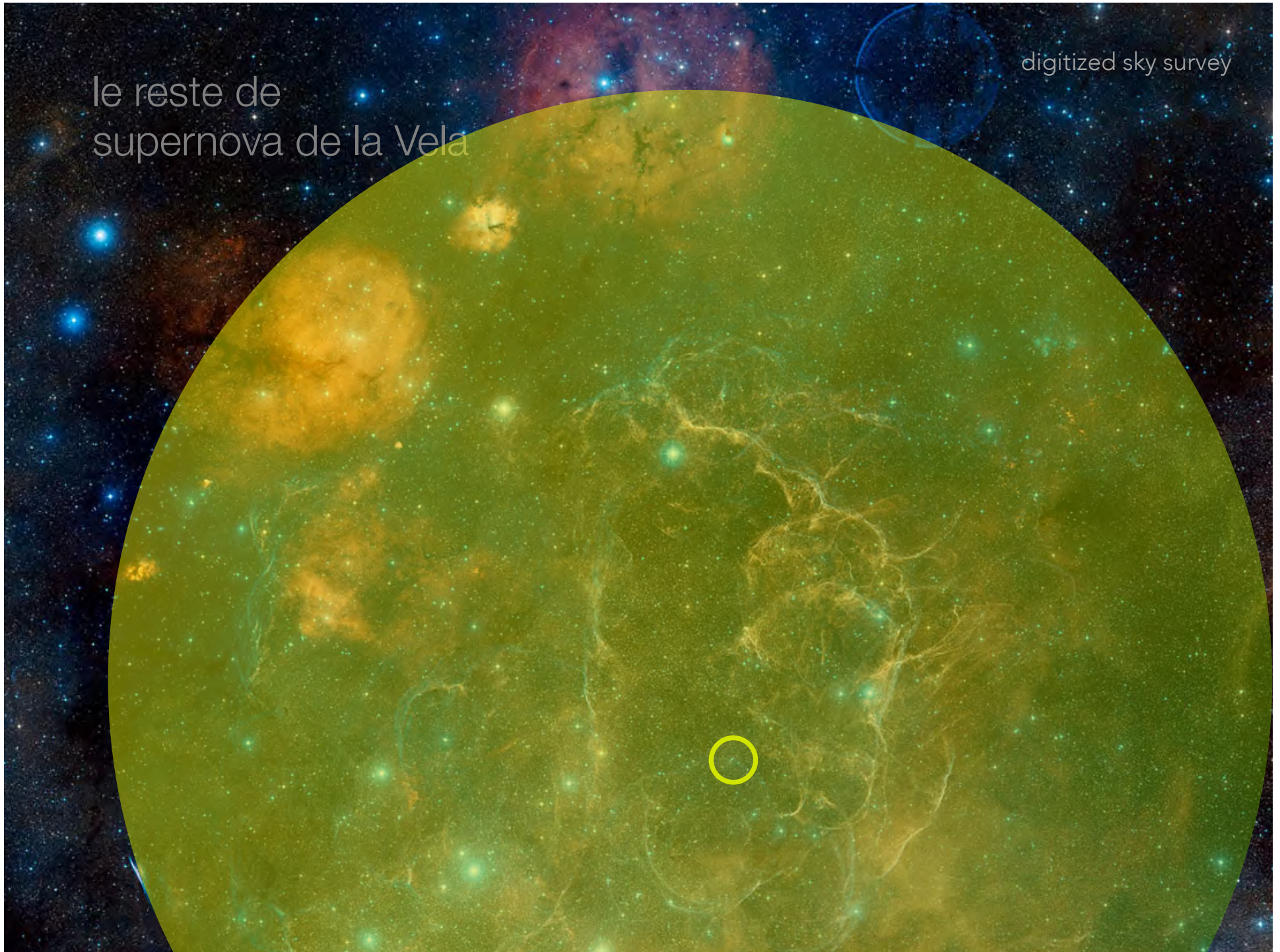


trous noirs
gaz chaud ds amas de gal.
restes de supernovae
disques et jets



le reste de
supernova de la Vela

digitized sky survey

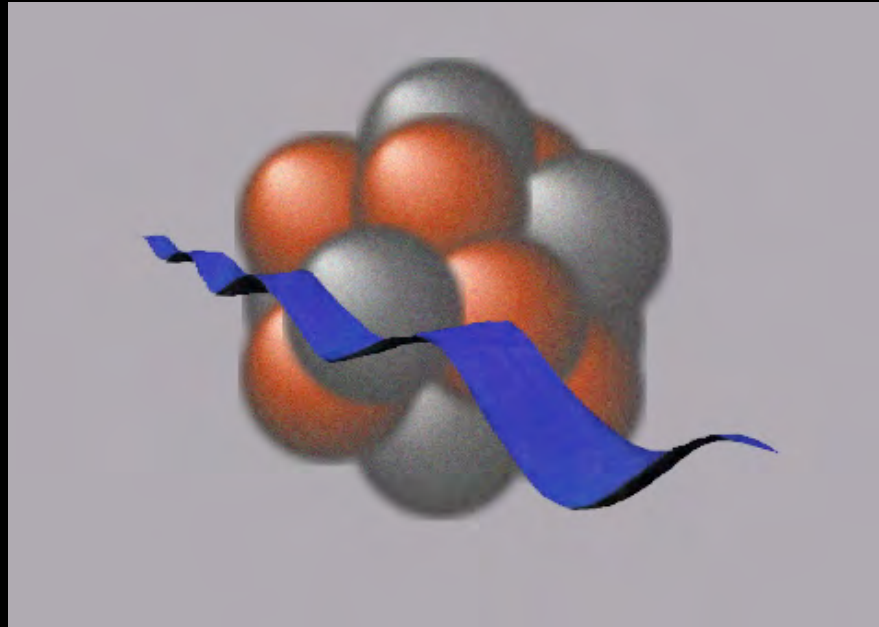


Swift J1644+57 : une nouvelle source de haute énergie dans le "dragon"

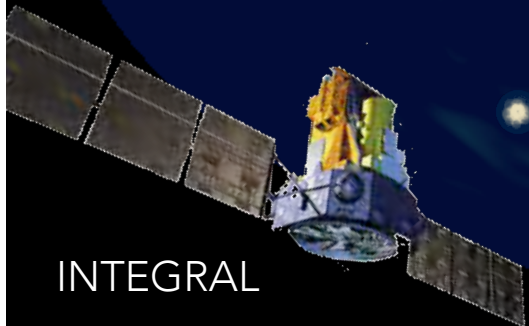


animation

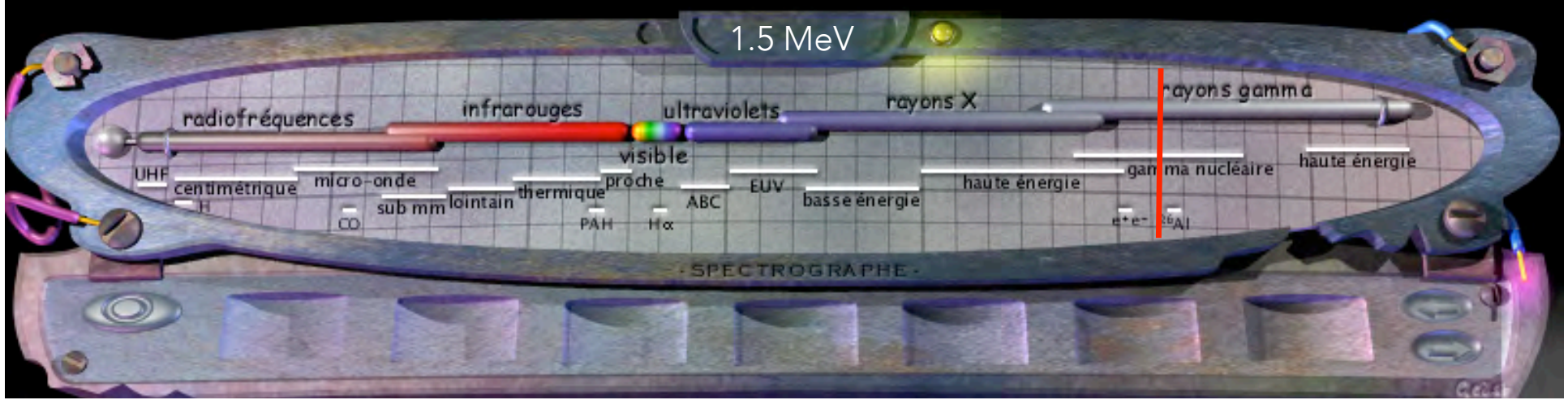
tableau de bord : rayons gamma



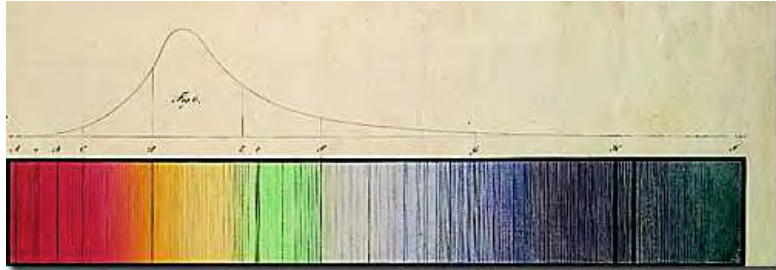
radioactivité
sursauts gamma
annihilation e^-e^+
magnetars ...



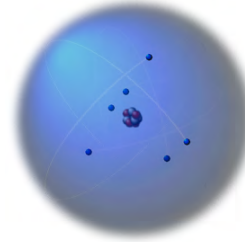
INTEGRAL



atomes et noyaux : niveaux énergétiques et résonances

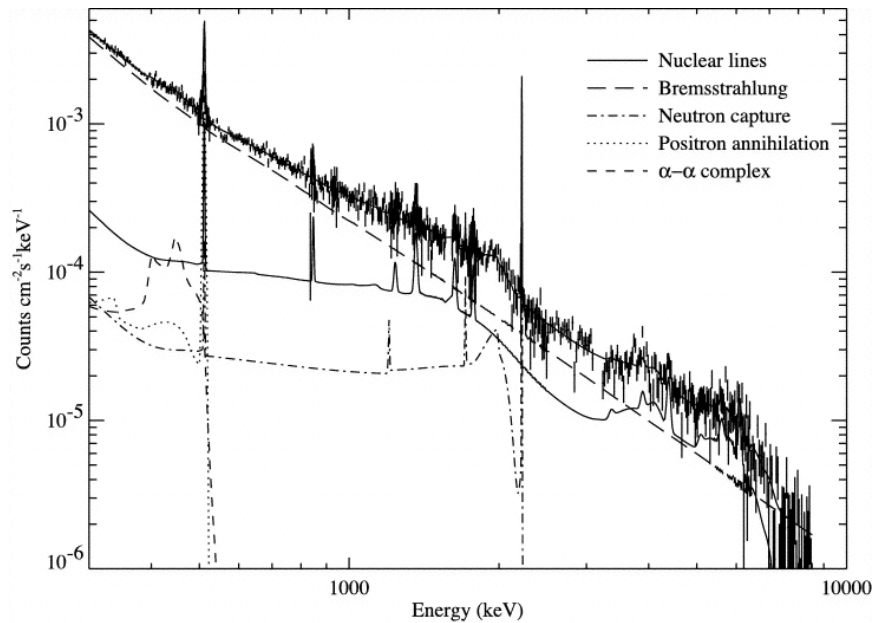


1814 Josef Fraunhofer

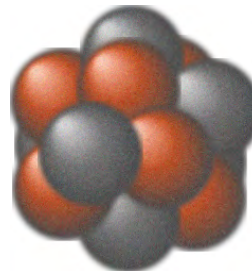


spectroscopie : outil pour l'étude des éléments chimiques dans les étoiles

-> physique atomique



2003 RHESSI (R. Lin et al. 2003)

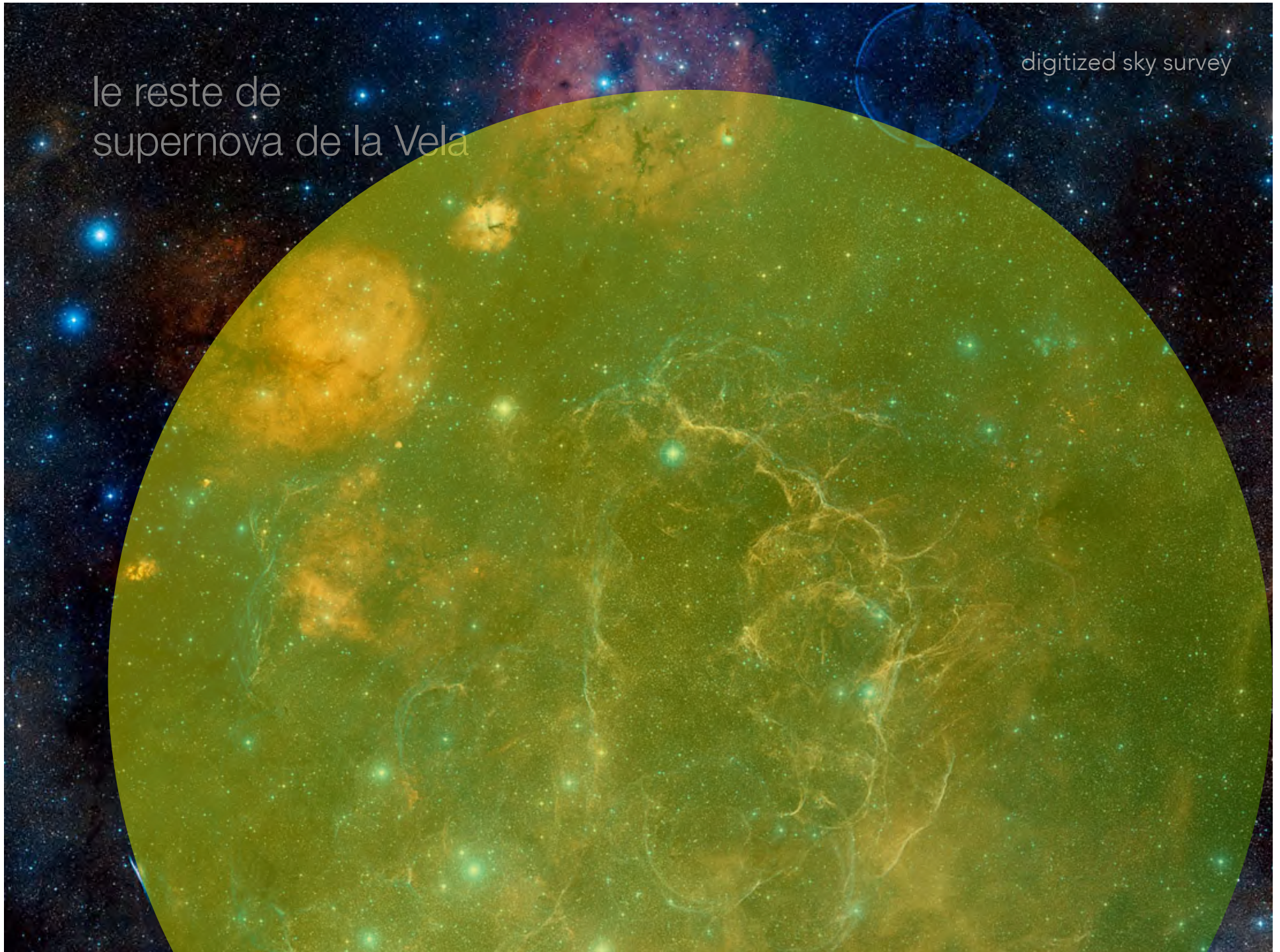


susaut solaire du 23.7 02 raies de desexcitation of Fe, Mg, Si, Ne, C, and O

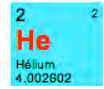
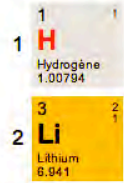
-> physique nucléaire !

le reste de
supernova de la Vela

digitized sky survey



les éléments chimiques



évolution stellaire - le cycle de la matière



Antimatière ?



quel rapport avec la lumière ?

Matière

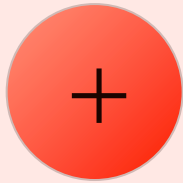
Antimatière

-

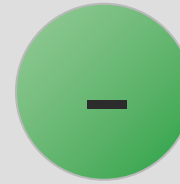
électron e^-

+

positron e^+



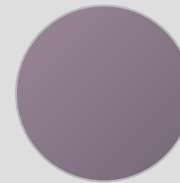
proton p^+



antiproton \bar{p}^-



neutron n



antineutron \bar{n}



photon γ



photon γ

les particules de matière et d'antimatière sont

opposés

et

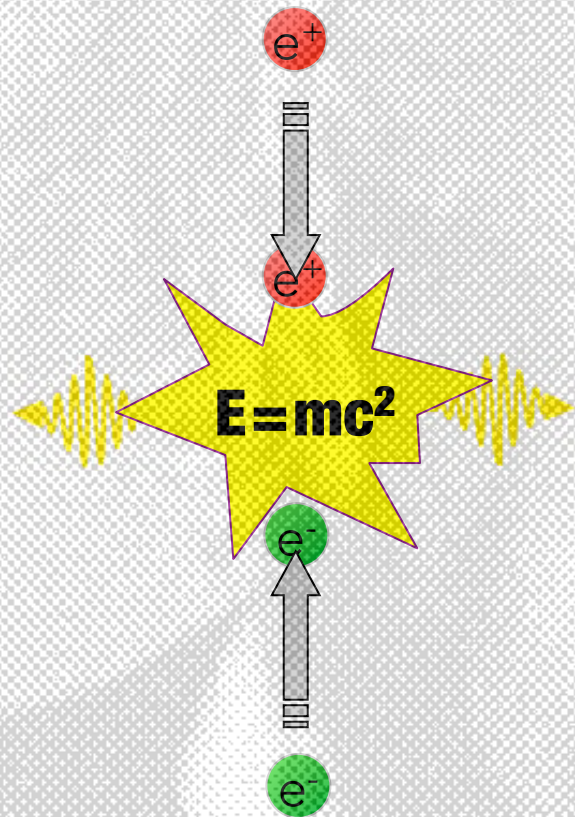
identiques

charge

masse

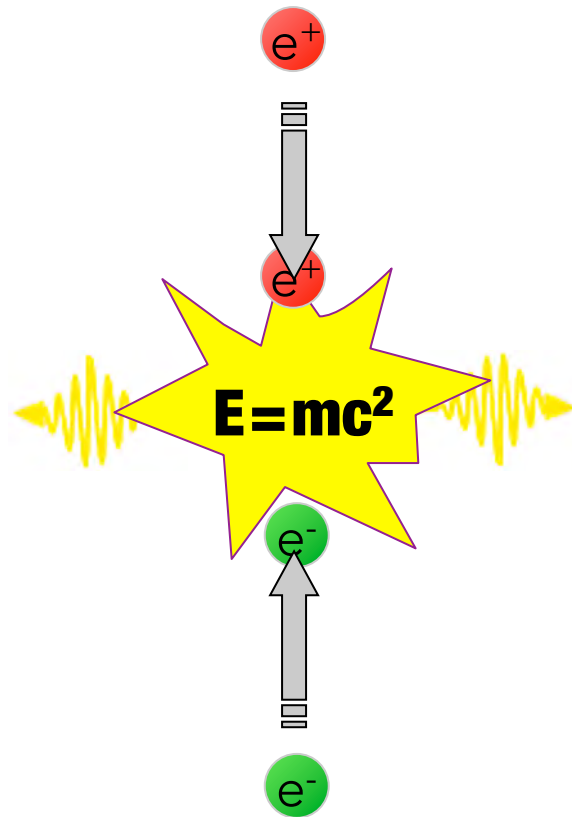
$$E = mc^2$$

l'annihilation e^+e^-



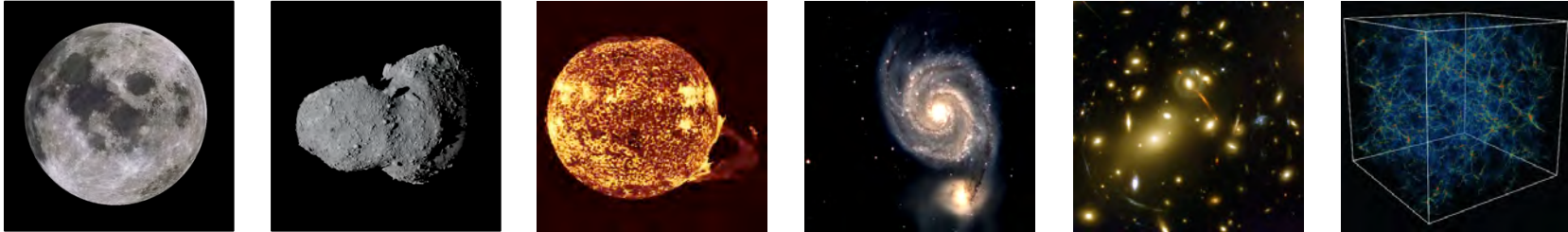
rayon γ

L'antimatière - comment l'observer ?

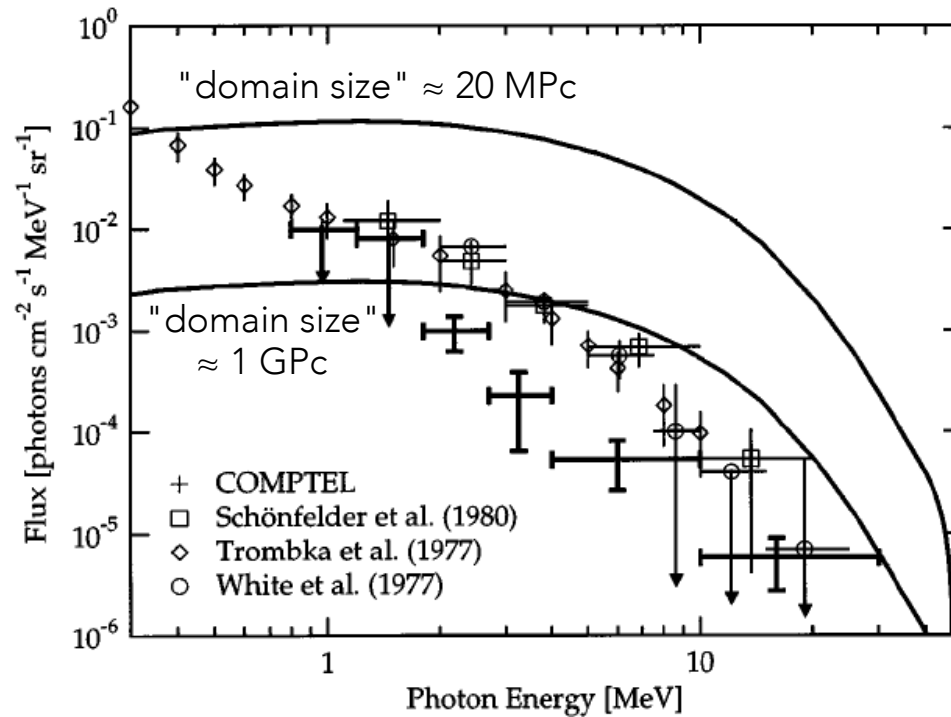


Où est l'antimatière ?

Notre Univers semble fait entièrement de matière :

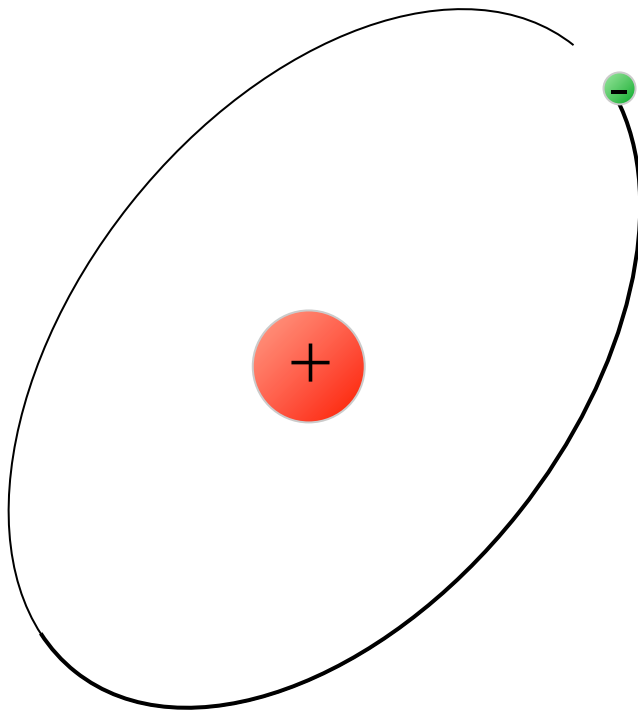


nous n'observons pas de γ signalant une frontière avec de l'antimatière

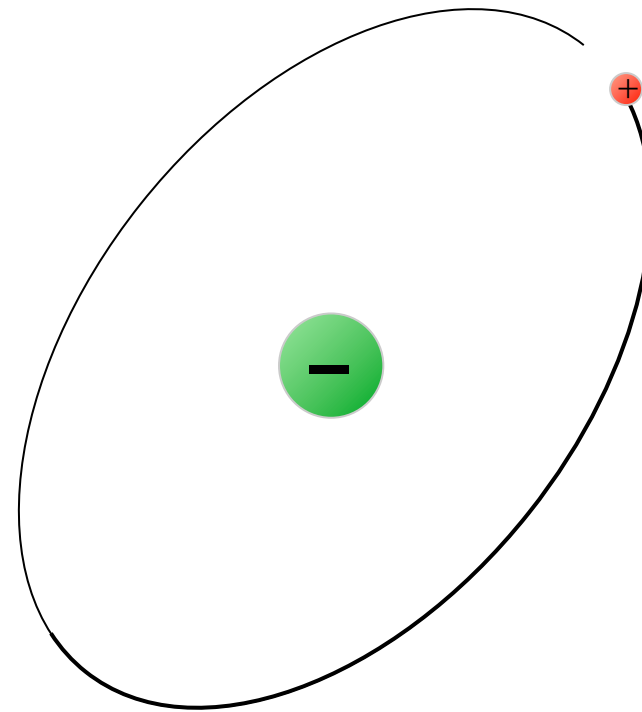


mesures et predictions

Des atomes d'antimatière - peut-on la fabriquer sur Terre ?

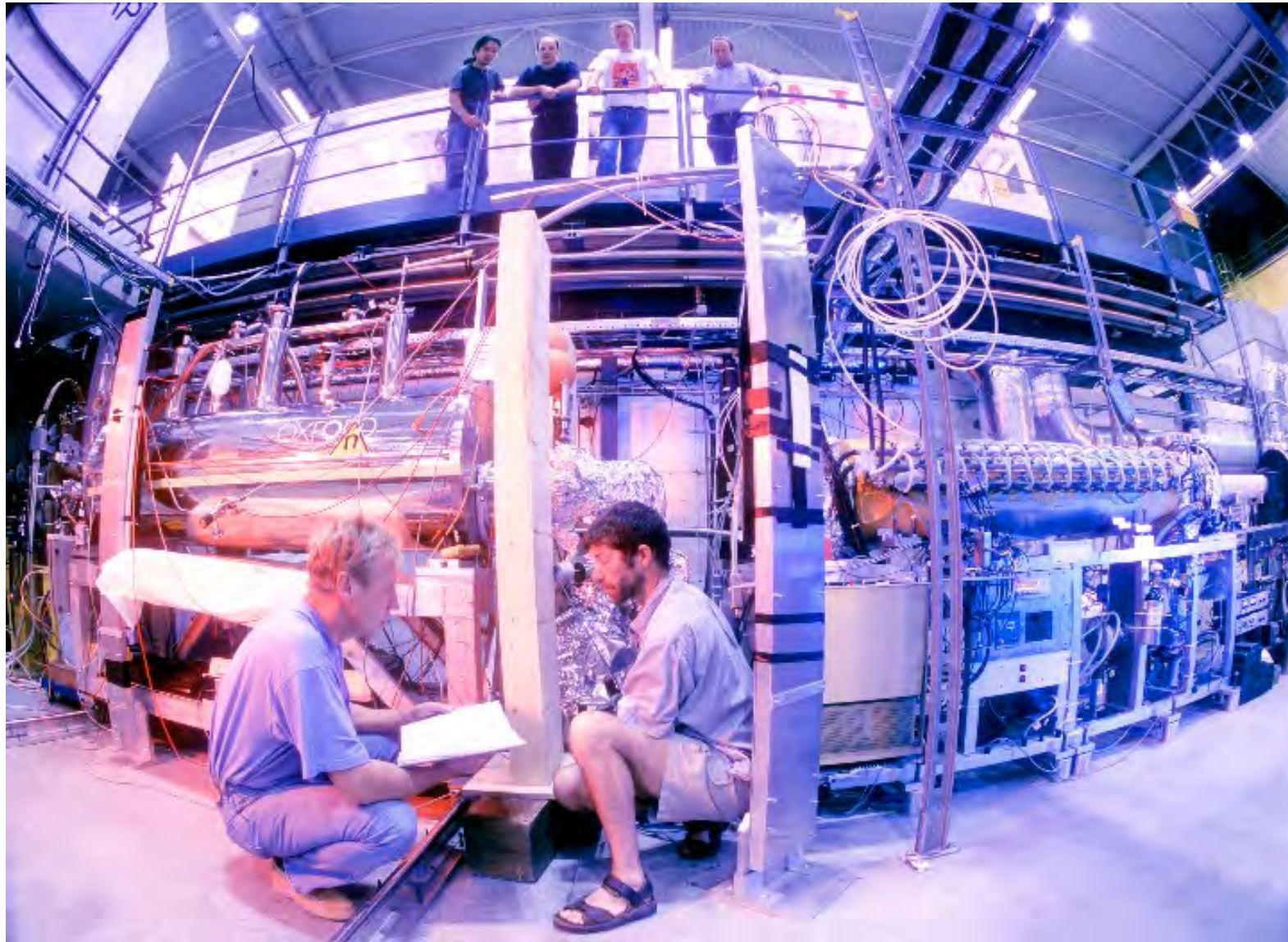


hydrogène

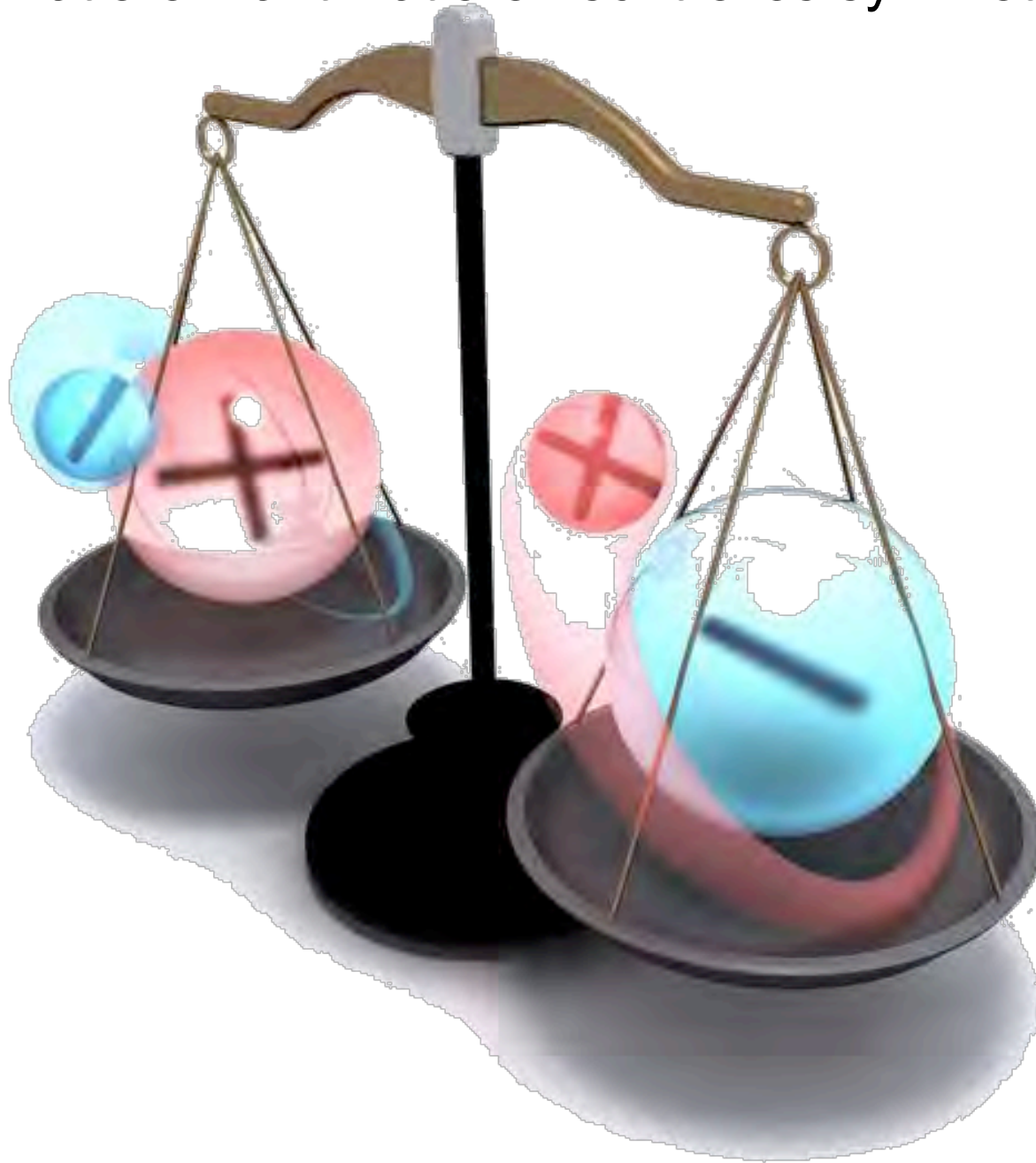


anti-hydrogène

l'expérience ATHENA

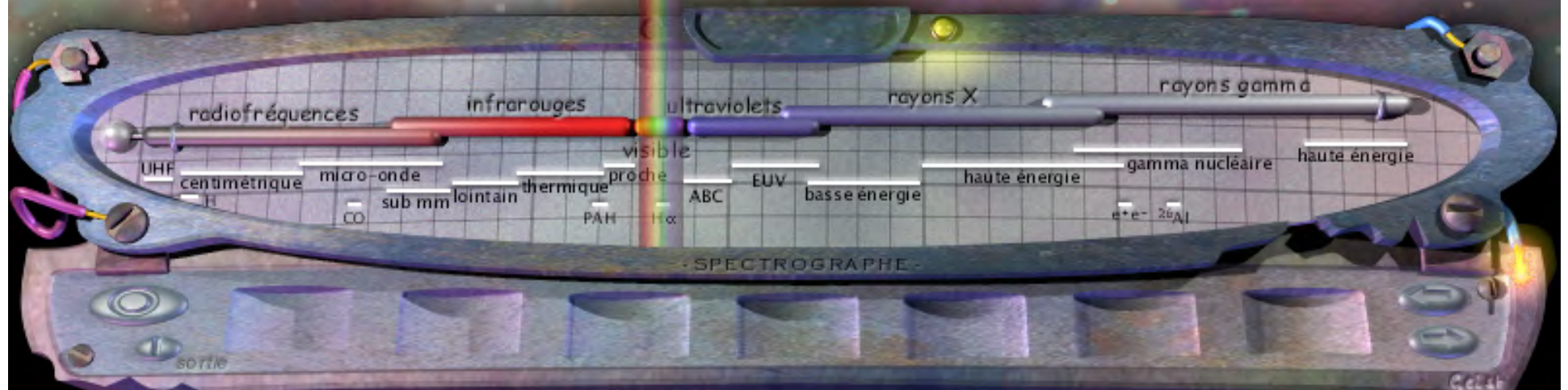
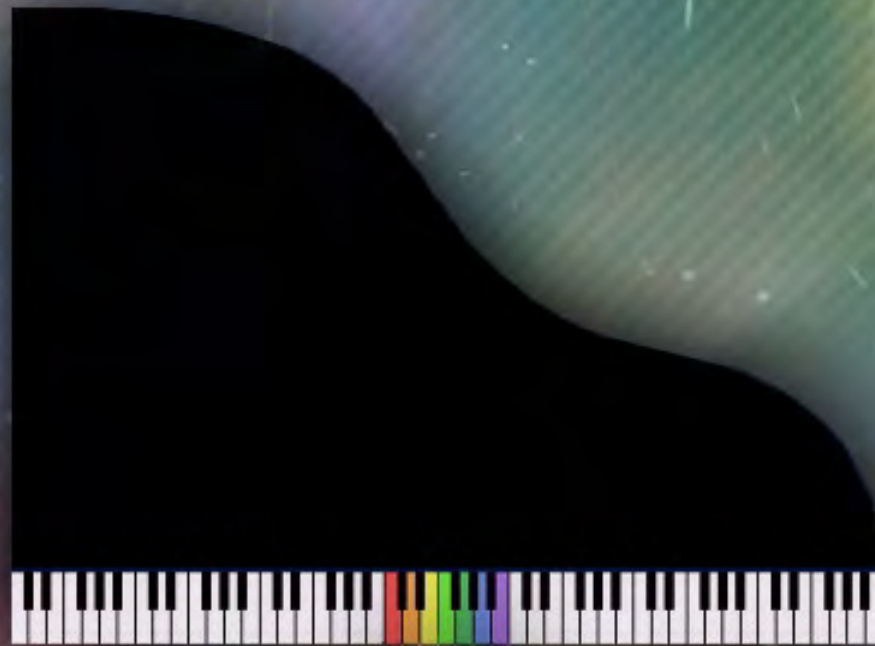


matière – antimatière : sont-elles symmetriques ?



comment imaginer l'invisible ?

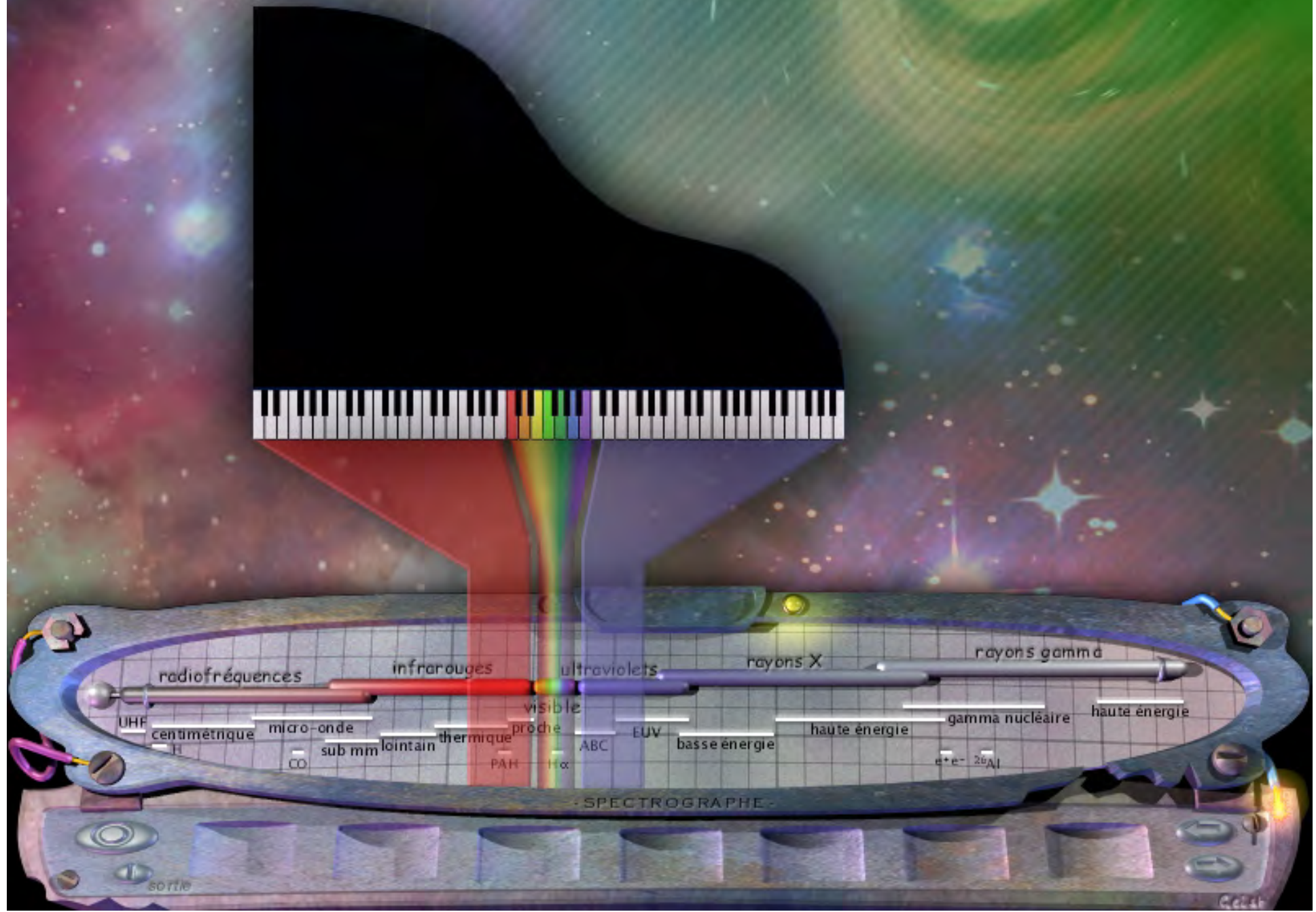
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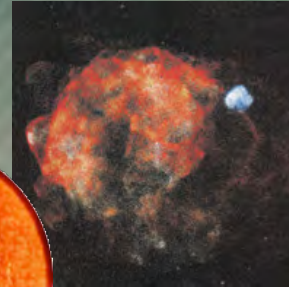
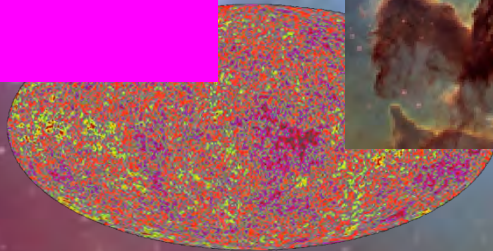
comment imaginer l'invisible ?

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comment imaginer l'invisible ?

Geist



4 % de ce qu'il y a dans l'Univers

La nature de la lumière

